63-3-5

RADC-TDR-63-85, Vol I

5 February 1963

MAINTAINABILITY TECHNIQUE STUDY
Final Technical Report
(PHASE V)

CONTRACT AF30(602)-2057

PREPARED FOR:

Rome Air Development Center
Research and Technology Division
Air Force System Command
United States Air Force
Griffiss Air Force Base, New York

PREPARED BY:

Government Services
RCA Service Company
A Division of Radio Corporation of America
Cherry Hill, Camden 8, New Jersey

RADC-TDR-63-85 Vol. I 5 February 1963

MAINTAINABILITY TECHNIQUE STUDY
Final Technical Report
Phase V

Government Services
RCA Service Company
A Division of Radio Corporation of America
Cherry Hill, Camden 8,
New Jersey

Contract AF30(602)-2057

Project Number: 5519
Task Number: 551901

Prepared

for

Rome Air Development Center
Research and Technology Division
Air Force Systems Command
United States Air Force
Griffiss Air Force Base
New York

MAINTAINABILITY TECHNIQUE STUDY

FOREWARD

The objective of this program was to investigate the factors which influence the maintainability of Air Force electronic equipment and further, to identify and measure these factors to provide a quantitative methodology for specifying and predicting the maintainability of new systems and equipment. These objectives were met through the implementation of a five (5) phase program. An extensive field data collection program, necessary because of the lack of basic time-to-repair data, made it possible to identify and measure the primary factors affecting ability to perform maintenance. Analysis of the data and application of statistical techniques resulted in the formulation of a Maintainability Prediction Technique, thus meeting the original program objectives.

The results of this study have already found application in a number of Air Force contracts and are reflected in the measurement and demonstration procedures described in Appendix A of Specification MIL-M-26512B "Maintainability Requirements for Aerospace Systems and Equipment." The results of this study will find greatest application to electronic systems. Further investigation is needed to prove its validity in electromechanical systems.

FRANK D. MAZZOLA, Project Engineer

The maintainability evaluation techniques presented in this report represents the combined effort of the following personnel:

Rome Air Development Center

F. D. Mazzola, Project Engineer, RASGR
R. J. Schiffler, RASHG

RCA Service Company

H. D. Voegtlen, Group Manager
B. L. Retterer, Project Manager
S. Bishop
K. B. Green
G. H. Griswold
L. W. Leidy
R. A. Miles
R. L. McLaughlin

Radio Corporation of America,
Defense Electronic Products

H. W. Kennedy
H. Dordick

Applied Psychological Services

A. I. Siegel

ABSTRACT

This report, contained in two volumes, summarizes the final results achieved in the performance of the Maintainability Techniques Study sponsored by the Rome Air Development Center under Contract AF30(602)2057. The broad objective of this study was the formulation of a maintainability technology applicable to ground electronic systems.

Volume I, describes the investigations made to (1) identify factors affecting maintainability, (2) specify maintainability on a quantitative basis, (3) improve design of ground electronic equipment, (4) predict maintainability of electronic systems, and (5) derive trade-offs relating reliability, maintainability, and other system parameters. Particular emphasis is given to the fifth phase of study which was devoted to validation of the prediction technique and the investigation of the Electronic Maintenance Proficiency Test. The volume is concluded by noting the current status of maintainability technology and recommending areas for additional research.

Volume II is a compilation of the analytical techniques and related maintainability information developed in the course of the study. Topics treated include: maintenance theory and classification, systems maintenance engineering, design guidelines, prediction technique, design review, demonstration testing, and field data acquisition. Collectively, this information forms a body of knowledge useful to the maintainability engineer.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES
(Continued)

MAINTAINABILITY TECHNIQUES STUDY
FINAL TECHNICAL REPORT
(PHASE V)

1. INTRODUCTION

1.1 Purpose of the Report

This report presents the final review of the results achieved in the performance of the Maintainability Techniques Study sponsored by the Rome Air Development Center under Contract AF 30(602)-2057. To provide maximum utility of the information derived, this report has been divided into two volumes. Volume I presents a complete review of the total program including the experimental procedure plus the results achieved. Considerable detail is provided concerning the validation work performed during Phase V of the research program. Volume II is a compilation of the maintainability engineering techniques developed by the study. It is intended that the second volume will form a ready reference document for the maintainability engineer.

1.2 Study Objectives

The maintainability technique study was directed toward the broad objectives of increased availability of Air Force systems, and the reduction of system support cost during service life. To achieve these objectives, means for quantitative evaluation and control of maintainability during the system life cycle were sought. Specifically, the study sought to accomplish the following:

a. Identification of the factors influencing maintainability and the formulation of methods for measuring the magnitude of these factors.

b. Development of mathematical relations between the maintainability factors and maintenance time, permitting the formulation of a prediction technique.

c. Establishment of means for specifying maintainability on a quantitative basis.

d. Providing criteria for design guidance to improve ground electronic equipment maintainability.

e. Deriving trade-off relations between reliability, maintainability, and cost.

The analytical tools provided by accomplishment of the above would contribute significantly to establishing maintainability as a well defined technology.

1.3 Study Program

The research program designed to accomplish the above stated objectives consisted of five formal stages as described below:

a. Phase I - Design of Research Plan

The plan formulated a group of factors believed to affect maintainability. Methods of information acquisition for laboratory experiments and field observation were developed. Techniques of analysis leading to the formulation of a prediction methodology were developed. Finally, a trial application and validation procedure was outlined. The Phase I portion of this research postulated many of the factors that affect maintainability, and developed preliminary methods of measurement for these factors.

b. Phase II - Field and Laboratory Data Collection

Three representative ground electronic equipments were selected as study vehicles. Information relative to equipment design, and support factors was collected at a number of operational field sites and at three semi-controlled laboratory locations. The approach consisted of measuring maintenance task performance during normal operation at field sites. For the laboratory programs, maintenance tasks were simulated through a carefully

designed schedule of malfunction or faults. For both field and laboratory programs maintenance task time measurements were recorded in conjunction with a quantitative evaluation of equipment design, scoring of personnel factors, and rating of support factors that affect the maintenance task.

During this phase certain modification of the measurement methods postulated during Phase I were accomplished. The relation of maintainability to the elements of design and logistic support were determined during the data collection and preliminary analysis phase of effort.

c. Phase III - Data Reduction and Analysis

During this phase a comprehensive analysis of all field and laboratory data was performed. Preliminary analyses of portions of the data were made and quantitative expressions for maintainability in terms of maintenance time were derived. The major elements of design, personnel, and support that contribute to time were isolated. Maintenance indices appropriate in describing maintainability were developed. These measures are useful in determining maintainability levels for present equipment, for comparison with other types of equipment within the Air Force inventory, and in establishment of state-of-the-art guidelines for evaluation of new designs and modification of support structure.

d. Phase IV - Development of Prediction Method

The information collected and reduced during Phases II and III constituted a body of knowledge from which the relation of equipment maintenance to design, personnel, and support factors was determined. Regression and correlation techniques were used to isolate the significant relations and to determine the relative magnitude of the many factors

that make up the numerical expression of maintainability. The prediction methodology developed will make possible design cycle control of new systems based upon quantitative knowledge of maintainability factors.

e. Phase V - Trial Application and Validation

This phase consisted of a trial application of the prediction method using an existing equipment not previously studied or evaluated for its maintainability. The prediction included both an early assessment based on preliminary system planning and a more detailed design review and prediction later in the development cycle. A field study was performed subsequent to the prediction. The data derived through the observation of actual maintenance activity, when compared to the predicted values, were significantly related. This finding established the validity of the technique.

1.4 Summary of Contents

This volume presents in Section 2 a review of the results achieved by the study. Comments are made concerning the degree to which each of the desired objectives were obtained. Section 3 contains a complete review of the major investigation phases accomplished during the course of the Phase V program. Included in this review are disscussions concerning the validation of the prediction technique, Electronic Maintenance Proficiency Test, investigating and general refinement of the developed maintainability technology. Section 4 reviews the current maintainability state-of-the-art and provides recommendations for continued research. Appendices I and II contains the supporting data used in the Phase V program.

2. PROGRAM RESULTS

2.1 Factor Identification

During the formulation of the program plan, it was recognized that maintainability could be evaluated in terms of several parameters including cost, time, and other important consequences. Of these, it was considered that time was the most basic and of immediate concern. The plan formulated called for a broad investigation of those factors which were considered directly to affect maintenance time. Figure 2.1, "Maintainability Factors," identifies those which were studied. It will be noted that equipment design, technical personnel, and the maintenance support environment, were considered the major parameters. Within each parameter, a number of factors, considered to influence maintenance time, were established. The identification of these factors thus fulfilled one part of the first program objective.

2.2 Measurement Techniques

2.2.1 Factor Measurement - To determine the relations of these factors to maintenance it was necessary to secure data concerning their magnitude. This was accomplished by developing a checklist for each factor. These checklists consisted of a series of questions appropriate to the factor being evaluated. These checklists, scored with reference to the factor characteristics for a particular task, provided a measurement of the maintenance condition. Scoring data for a large group of tasks thus provided information which, when subsequently analyzed, permitted the relating of the maintenance factors to maintenance time.

2.2.2 Time Measurement - Supplementary to the factor measurement, time data concerning maintenance performance was obtained. Standard time study techniques were utilized to develop all task time measurements. A work sampling plan was utilized to analyze the total activity of the maintenance technicians assigned.

2.2.3 Profficiency Measurement - Within the personnel area, the Electronics Maintenance Profficiency Test (EMPT),

MAINTENANCE PARAMETERS		
DESIGN	PERSONNEL	SUPPORT
1. Physical Design Features 2. Design Dictates-Facilities 3. Design Dictates-Skills	1. Coordination 2. Attitude-Motivation 3. Proficiency Test 4. Biographical	1. Technical Data 2. Supply 3. Test Equipment 4. Organization

FIGURE 2.1. MAINTAINABILITY FACTORS

was a specially constructed measurement device designed to assess technical capability. This test was patterned after intellegence tests but was developed in an electronic context.

2.2.4 The formulation of these measurement techniques completed the first program objectives. After initial establishment, refinement of the techniques was accomplished several times during the program.

2.3 Prediction Relations

The time and scoring data collected in the course of the field program were submitted to a simple correlation analysis to identify those factors affecting maintenance time. Factors which appeared to relate significantly, were then submitted to a partial correlation analysis to remove interactive effects. Table 2.1,"Partial Correlation Coefficients," presents the results of this analysis. Here, the entries A, B, C_1, and C_2 represent the design

TABLE 2.1
PARTIAL CORRELATION COEFFICIENTS
(N = 101)

	A	B	C1	C2	S	Z
A	-	.07034	.02057	.01043	.01407	-.55804**
B		-	.23063*	-.30900**	.29283**	-.27893**
C1			-	.33358**	.00536	-.04668
C2				-	.20207*	-.16162
S					-	-.18906
Z						-

** 1% Sig. = .260
 * 5% Sig. = .200

factors while S is a composite measure of the support environment. Maintenance time is denoted as Z which is the log of real down time values. This examination showed that of physical design features (A) and facilities

requirements (B) were related to maintenance time with design dictates-skills (C_2) and support (S) as possible contributors. Subsequent examinations established factors A, B, and C_2 to be the best combination for system design phase prediction. A mathematical equation embodying these terms was developed, permitting the formulation of the prediction technique, thus fulfilling the second program objective.

2.4 Time Specification

From the study, the characteristics of maintenance time were determined, thus leading to a system of time indices. The suitability of the log-normal distribution as a descriptive parameter was established. Figure 2.2, "Frequency Distribution of Down Time," illustrates a typical observed log-normal relation. Through the detailed examination of the maintenance process an appropriate classification method was developed, providing a means for maintenance time specification. This development fulfills the third program objective.

2.5 Design Criteria

From the data gathered in the study, information useful for formulating design guidelines was obtained. These guidelines take several forms. First, within the design area, an ordered list of features has been developed which permits decisions to be made concerning the relative importance of alternate designs. Within the personnel area, information concerning the average maintenance man has been formulated to assist the designer in developing equipment commensurate with available skills. Checklist data developed for the support area forms a means of assessing the design-support environment compatability. Jointly, the criteria provide information concerning design, personnel, and support which will assist the designers in developing a system compatable with the major factors affecting maintainability. These design criteria fulfilled the fourth program objective.

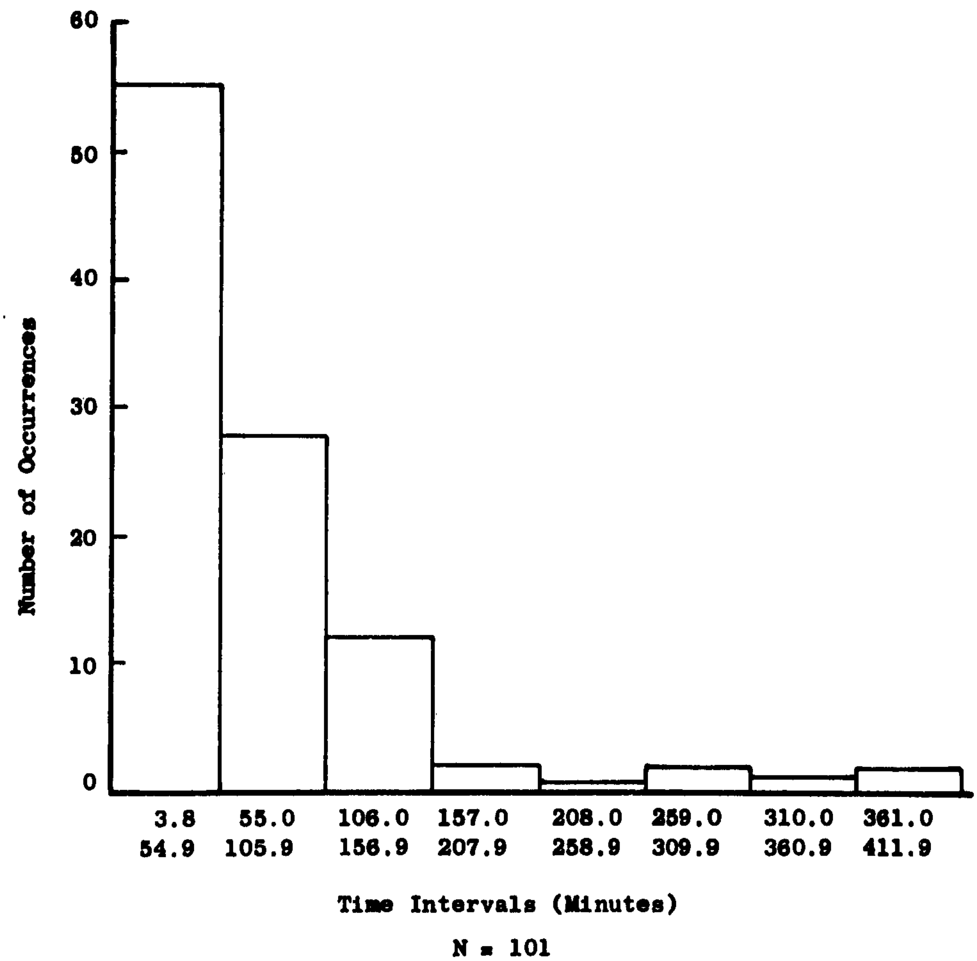

FIGURE 2.2. FREQUENCY DISTRIBUTION OF DOWN TIME

2.6 Trade off Techniques

The prediction technique permits the examination of maintainability design and support features in terms of maintenance time. Through the use of the availability relation between reliability and maintainability, it is possible to investigate the impact of such features at the system level. Repeated investigation of alternate configurations, permits optimum selections to be made. Additionally, cost implications may be included in the examinations, thus providing optimization among major system parameters. This technique fulfills the final objective of the study.

2.7 Summary

The preceding discussion has highlighted the results of the maintainability study. Information concerning their application is contained in Volume II. Details concerning their development are contained in Section 3 of this report and previous contract reports.[1,2,3,4]

3. PHASE V PROGRAM

3.1 General

The Maintainability Technique Study began June 1959 after the award of contract AF30(602)-2057 to the RCA Service Company. The preliminary plan, outlined in the RCA Proposal (30 DEP-29) to the Rome Air Development Center (RADC), was designed as a five phase effort responsive to the desired RADC objectives. These five phases are listed as follows:

- I Design of the Research Plan
- II Field Data Collection and Laboratory Programs
- III Reduction and Analysis of Data to Maintainability Indices
- IV Development of Prediction Technique
- V Trial Application and Validation

Most of the ground rules and major decisions relative to basic approaches were initiated in the first and second phases of the program. The results of the first four phases of this program have been documented in previously issued reports.[1,2,3,4] The fifth and final phase of this program is described in the following paragraphs.

3.2 Phase V Objectives

The final phase of this program had three major objectives:

a. Validation of the maintainability prediction technique

b. Validation of the Electronic Maintenance Proficiency Test (EMPT)

c. Refinement of other techniques developed during the program

The validation of the prediction technique was to be accomplished by comparing predictions made on equipment, not previously evaluated, with data obtained from field operation. The validity of the EMPT was to be established through the comparison of scores achieved by a selected group of civilian technicians with the total time required for each technician to perform a group of representative maintenance tasks. Other techniques were refined through further analysis of the data obtained during the first four phases of the program and through evaluation of other work accomplished in the field of maintainability.

3.3 Maintainability Prediction Technique

The prediction technique chosen was based on linear regression. The linear regression process involves finding a relation between several independent variables and one dependent variable. In this case time was the dependent variable and the checklists were the independent variables. The process of development of this approach is described in the paragraphs below.

3.3.1 Background - The four months following the award of the contract were devoted to the development of a detailed research plan. This effort involved the development of a technical approach, generation of data collection devices, selection of field and laboratory equipments, selection of sites, selection and training of observer personnel, and the establishment of a program schedule.

3.3.1.1 Following the planning stage, a field study program was instituted to gather data on the maintenance process. These data were gathered on the AN/GKA-5 data link, the AN/FST-2 data processor, and the AN/FPS-20 search radar at eight Air Force sites in the continental United States. Through the field program, corrective, preventive, and modification tasks were monitored, timed and scored. Information relative to environmental conditions, equipment background, operating conditions, personnel characteristics, and the support situation was gathered at each site prior to the look into the maintenance activity and task performances. After careful screening of all data submitted by the field observers, a total of 101 corrective maintenance

tasks and 42 preventive maintenance tasks were found suitable for use.

3.3.1.2 The next step in the development of the prediction technique was to determine the distributions of the parameters and the relations between them. The distribution of down time was found to be log-normal, while each design checklist and the total of the support checklists were normally distributed. A correlation analysis performed between down time corrective maintenance actions only and three of the design checklists established the checklists as the best predictors of down time. This analysis is described in detail in the phase IV progress report, "Maintainability Prediction Technique." (4)

3.3.1.3 The final step was to develop a prediction equation and evolve a process for applying it. A regression analysis was performed between the selected design checklists and active corrective maintenance down time. This analysis resulted in the following prediction equation:

$$\text{Log } M_{ct} = 3.54651 - 0.02512\ A - 0.03055\ B - 0.01093\ C \quad (3.1)$$

Where:

$\text{Log } M_{ct}$ = Logarithm of corrective active down time

A = Physical design factors score

B = Design dictates - Facilities score

C = Design dictates - Maintenance skills score

A procedure was then developed to apply this equation in the evaluation of an equipment during its design cycle. This procedure is described in detail in Section 5, Volume II, of this report.

3.3.2 Trial Prediction - The first step in the validation of the maintainability prediction technique was to perform an analysis of two equipments not previously evaluated, using data normally available during the design phase. The AN/FPS-6 height-finder radar and the AN/GRT-3/GRR-7

communications equipments were selected as the vehicles for performing the validation. The following paragraphs describe in detail the application of the prediction technique to each of these equipments.

3.3.2.1 AN/FPS-6 Radar - The equipment is an air-transportable, high-power, long-range fixed-station, height finder for use in association with a search radar of comparable range capability. The equipment is installed with its antenna and radio frequency units mounted on a tower, and its control and indicating units installed in the operations building of the associated search radar. The equipment has an average complexity of 3150 parts and maintenance is performed on the part basis. Power requirements are 50 kilowatts of 120/208volts, 3 phase at 60 cycles. The equipment can operate in temperate, arctic, and tropical climates.

3.3.2.1.1 Types of Predictions - Two predictions were made for the AN/FPS-6 equipment corresponding to the following equipment development periods:

a. Ninety days after award of contract or at completion of the paper design of the contract article.

b. Sixty days prior to delivery of the contract article.

The prediction made at the stage (a) constitutes a preliminary estimate based on limited knowledge of circuit configuration and with general guidelines for the packaging concepts. Stage (b) was a prediction which makes use of the full design information. All information used for the maintainability prediction of this equipment was obtained from the applicable Air Force Technical Orders.

3.3.2.1.2 Preliminary Prediction, AN/FPS-6 - The following detailed information was used to accomplish the preliminary prediction:

a. Functional block diagram

b. Estimated part complexity for each functional block

c. General theory of operation

d. Exterior views of all major assemblies

e. Description of general construction techniques to be used

f. Description of displays and controls to be provided

g. Assumption that a test point is available at the output of each functional block, and

h. List of tools and test equipment available.

3.3.2.1.3 After familiarization with the information supplied, the first step was to predict the failure rate of each functional block. This was accomplished by multiplying the part class complexities by average failure rates obtained from field data for radar equipment. A sample size of 20 was selected on the basis of 90% confidence and 40% accuracy and this sample was distributed among the functional blocks in accordance with their percentage contribution to the equipment failure rate. Table 3.1, "AN/FPS-6 Functional Block Failure Distribution," shows the sample selection. Part types for failures were randomly assigned to the selected sample in accordance with the following distribution: 15 electron tubes, 2 resistors, 1 capacitor, 1 N-type diode, and 1 relay. (Past reliability history of similar equipments indicates this to be a typical breakdown of 20 consecutive failures.) For each part a typical failure mode for the particular part type and circuit function was assumed and the symptoms of the failure were determined. A maintenance analysis was performed for each assumed failure and from this analysis and the technical information supplied, the design checklists were scored. In cases where there was insufficient information to score a particular checklist item, the item was given the average score for the items in the checklist that could be scored for that particular task. The last step was to predict the down time for each task by inserting the checklist scores in the prediction equation. The data derived from this prediction are shown in Table 3.2, "AN/FPS-6 Preliminary Prediction."

TABLE 3.1

AN/FPS-6 FUNCTIONAL BLOCK FAILURE DISTRIBUTION

Functional Block	Part Complexity	Fail. Rate %/1000 Hrs.	% Contri-bution	Failures for Sample of 20	Actual Sample Size
Mod. Assembly					
Mod. Trig. Amp.	47	10.932	2.13	.43	1
Mod. Control Circuit	67	15.348	2.98	.60	1
Pulse Form. Network	46	6.151	1.20	.24	0
Modulator H.V. Supply	23	10.819	2.10	.42	0
Modulator H.V. Regulator	4	.409	.07	.01	0
Magnetron Assembly					
Mag. Assembly	31	2.964	.58	.12	0
R. F. Assembly					
Duplexer	1	.178	.03	.06	0
Power Supply	68	23.721	4.61	.92	1
AFC-Loc. Osc.	45	8.854	1.72	.34	0
Mixer & Pre-I.F. Amp.	97	17.120	3.33	.66	1
Control Group Assembly					
Power Supply	83	20.371	3.96	.79	1
Range Mark Gen.	85	17.423	3.39	.68	1
I.F. Amp. & Detector	193	39.366	7.65	1.53	2
Elev. Data Gen.	44	7.435	1.45	.29	0
Interf. Blanker	77	12.373	2.41	.48	1
Ant. Elev. Control	3	.135	.03	.06	0
Angle Mark Gen.	42	6.952	1.35	.27	0
Azimuth Serv. Amp.	132	23.346	4.54	.91	1

TABLE 3.1 (CONT.)

Functional Block	Part Complexity	Fail. Rate %/1000 Hrs.	% Contri-bution	Failures for Sample of 20	Actual Sample Size
Range-Height Ind. Assy.					
Horz. Sweep Gen.	166	33.570	6.53	1.31	1
Sweep & Int. Gate Gen.	142	30.030	5.84	1.17	1
Vertical Sweep Gen.	180	36.824	7.16	1.43	1
Height Line & Mark Gen.	168	27.375	5.32	1.06	1
Video Amp.	82	13.728	2.67	.53	1
Range Data Amp.	46	7.056	1.37	.27	0
Angle Mark Amp.	52	10.156	1.97	.39	0
Power Supply	218	69.174	13.45	2.69	3
Time Sharing Group					
Remote Height Display	196	42.648	8.29	1.66	2
Azimuth Control Display	12	1.512	.29	.06	0
Junction Box	43	7.981	1.55	.31	0
Time Sharing Master Cont.	35	9.149	1.78	.36	0
Antenna Assembly	11	1.294	.25	.05	0
Total	2439	514.394	100.00	20	20

TABLE 3.2

AN/FPS-6
PRELIMINARY PREDICTION

Task	Circuit Function	Part Type	A	B	C	Log M_{ct}	M_{ct}
1	Mod.Trigger Amp.	Res.	28	23	19	1.93283	85.7
2	Modulator Control	Tube	42	26	27	1.40206	25.2
3	Power Supply	Relay	36	24	16	1.73411	54.2
4	Mixer-Amplifier	Tube	44	26	17	1.46112	28.9
5	Power Supply	Tube	42	25	16	1.55284	35.7
6	Range Mk. Gen.	Tube	43	25	20	1.48400	30.5
7	IF Amp. & Detect.	Tube	45	25	18	1.45562	28.6
8	IF Amp. & Detect.	Tube	42	23	18	1.59208	39.1
9	Interfer.Blanker	Tube	45	25	17	1.46655	29.3
10	Az. Servo Amp.	Tube	44	21	20	1.58108	38.1
11	Horiz.Sweep Gen.	Tube	42	26	18	1.50043	31.7
12	Sweep Gate Gen.	Res.	40	25	11	1.65773	45.5
13	Vert. Sweep Gen.	Tube	44	25	14	1.52446	33.5
14	Ht. Mk. Gen.	Tube	44	25	14	1.52446	33.5
15	Video Amplifier	Tube	40	23	14	1.68604	48.5
16	Power Supply	Tube	38	26	17	1.61184	40.9
17	Power Supply	Tube	46	26	24	1.33437	21.6
18	Power Supply	Diode	40	24	18	1.61177	40.9
19	Remote Ht.Displ.	Cap.	34	25	11	1.80845	64.3
20	Remote Ht.Displ.	Tube	44	26	22	1.40647	25.5

Operation	A	B	C	Log M_{ct}	M_{ct}
S	823.0	494.0	351.0	31.32831	781.2
SS	34,231.0	12,236.0	6,455.0	49.47638	34,882.80
$S^2/20$	33,866.45	12,201.80	6,160.05	49.07315	30,513.67
SSD	364.55	34.20	294.95	0.40323	4,369.13
σ^2	19.19	1.80	15.52	0.02122	229.95
σ	4.38	1.34	3.94	0.14568	15.16
$\bar{S}$	41.15	24.70	17.55	1.56642	39.06
c	0.11	0.054	0.22	0.093	.39
M_{max}	-	-	-	2.34963 $\longrightarrow$	223.7

3.3.2.1.4 From the data derived in the above prediction maintainability indices were calculated. The mean down time was calculated by dividing the total down time (781.2 minutes) by the sample size (20) to obtain 39.1 minutes. The maximum down time (M_{max}) was calculated using the following equation:

$$M_{max} = 1.5\ \overline{\log M_{ct}} \tag{3.2}$$

Where:

$\overline{\log M_{ct}}$ = mean of the log down times

Using the data from Table 3.2 a value of 223.7 minutes was computed.

3.3.2.1.5 Full Design Prediction, AN/FPS-6 - The full design prediction was accomplished by using the complete information available from the equipment technical orders. The first step was to make a part count from the Illustrated Parts Breakdown (T.O. 31P3-2FPS6-4) to determine equipment complexity by part class. From this the total failure rate for each part class was determined, using average rates from reliability field data. A sample size of 50 was selected on the basis of 90% confidence and 25% accuracy. The percent contribution of part class failure rates to equipment failure rate was used to determine the distribution of part types in the sample of 50. Table 3.3, "AN/FPS-6 Failure Distribution," shows the failure rate computation and the sample selected. The next step was to select, randomly, the sample parts from the total equipment population. This was accomplished with the aid of a table of random numbers. After the sample was selected a typical failure mode was assumed for each part and the symptoms of equipment failure determined. A maintenance analysis was performed for each sample part and the design checklists scored, using the maintenance analysis and the information available from the technical orders. The final step was to insert the checklist scores in the prediction equation for each task and compute the expected down time. The data derived from this prediction are shown in Table 3.4, "AN/FPS-6 Maintainability Prediction."

TABLE 3.3

AN/FPS-6 FAILURE DISTRIBUTION

Part Class	Symbol	Quan.	Average Part Failures %/1000 Hrs.	No.of Exp. Fail. Per 1000 Hrs. Operation	Contri.to Total Expected Fail. (%)	No. of Fail. for Sample of 50	Actual Failures
Blowers/ Motors	B	44	.189	.083	1.30	.65	1
Capacitors	C	505	.010	.051	.80	.40	0
N-type Diodes	CR	19	2.983	.567	8.87	4.44	4
Connectors	J	261	.032	.084	1.31	.66	1
Relays	K	74	.359	.266	4.16	2.08	2
Coils	L	71	.033	.023	.35	.18	0
Resistors	R	1517	.015	.228	3.57	1.79	2
Switch	S	176	.045	.079	1.24	.62	1
Trans- formers	T	85	.133	.113	1.77	.89	1
Tubes	V	301	1.567	4.717	73.81	36.91	37
Misc.	-	101	.178	.180	2.82	1.41	1
Total		3154		6.3910	100.00		50

TABLE 3.4

AN/FPS-6
MAINTAINABILITY PREDICTION

Task	Major Unit	Ass'y.	Part	Checklist Score A	B	C	Log M_{ct}	M_{ct}
1	OA-270	IP-188	V-4008	38	25	21	1.59867	39.7
2	OA-270	PP-795	V-4102	36	25	19	1.67077	46.9
3	OA-270	PP-795	V-4104	40	25	18	1.58122	38.1
4	OA-270	PP-795	V-4106	36	23	13	1.79745	62.7
5	OA-270	PP-795	V-4110	46	26	16	1.42181	26.4
6	OA-270	PP-795	V-4111	46	26	21	1.36717	23.3
7	OA-270	PP-795	R-4110	32	23	11	1.91979	83.1
8	OA-270	PP-828	CR-4151	25	23	11	2.09563	124.6
9	OA-270	IP-188	V-4306	41	23	7	1.73743	54.6
10	OA-270	IP-188	V-4402	43	23	16	1.58882	38.8
11	OA-270	IP-188	V-4403	41	23	11	1.69371	49.4
12	OA-270	IP-188	V-4407	41	23	16	1.63906	43.6
13	OA-270	IP-188	V-4604	41	25	19	1.54517	35.1
14	OA-270	IP-188	V-4701	41	23	14	1.66092	45.8
15	OA-270	IP-188	V-4703	41	23	13	1.67185	47.0
16	OA-270	IP-188	V-4802	48	26	23	1.29506	19.7
17	OA-270	IP-188	V-4805	42	23	17	1.60301	40.1
18	OA-270	IP-188	V-4903	43	25	18	1.50536	32.1
19	OA-320	TS-735	V-5210	37	21	12	1.84436	69.9
20	OA-320	TS-735	V-5213	37	21	16	1.80064	63.2
21	OA-320	MX-1316	V-5503	41	23	18	1.61720	41.4
22	OA-320	MX-1316	V-5504	41	23	16	1.63906	43.6
23	OA-320	MX-1316	V-5506	39	23	20	1.64558	44.2
24	OA-320	AM-646	V-6003	32	19	11	2.04199	110.2
25	OA-320	AM-646	V-6006	30	23	17	1.90445	80.3
26	OA-320	AM-622	V-21705	41	21	18	1.67830	47.7
27	OA-320	AM-622	V-21714	36	25	18	1.68170	48.1
28	OA-320	MX-1359	T-5601	30	17	11	2.15333	142.3
29	OA-357	PP-755	V-1104	39	25	21	1.57355	37.5
30	OA-357	PP-755	K-1101	40	24	23	1.55712	36.1
31	OA-357	PP-755	V-1110	37	26	16	1.64789	44.5
32	OA-357	PP-755	V-1112	39	25	22	1.56262	36.5
33	OA-357	O-166	V-21303	31	19	9	2.08897	125.6
34	OA-357	O-166	R-21304	26	18	8	2.25605	180.3
35	OA-357	CV-218	V-21505	37	23	16	1.73954	54.9
36	OA-357	CV-218	V-21506	37	23	18	1.71768	52.2

TABLE 3.4 (CONT.)

Task	Major Unit	Ass'y.	Part	A	B	C	Log M_{ct}	M_{ct}
37	OA-357	CV-218	CR-21501	35	24	18	1.73737	54.6
38	OA-329	AM-654	V-2004	30	15	7	2.25815	181.2
39	OA-329	CN-187	CR-2101	36	19	11	1.94151	87.4
40	OA-329	CN-187	CR-2102	18	12	7	2.65124	448.0
41	OA-329	CY-1138	S-2204	41	25	25	1.47959	30.2
42	PP-783	PP-793	V-10402	39	23	13	1.72209	52.7
43	C-1048	C-1048	B-3901	34	23	23	1.73839	54.8
44	CN-93	CN-93	J-10303	28	23	16	1.96562	92.4
45	J-470	J-470	K-9710	38	26	24	1.53533	34.3
46	PU-292	PU-293	Z-3507	28	23	16	1.96562	92.4
47	ID-331	ID-331	V-3701	43	23	17	1.57789	37.8
48	ID-331	ID-331	V-3703	44	23	18	1.54184	34.8
49	ID-331	ID-331	V-3704	42	23	17	1.60301	40.1
50	C-1049	C-1049	V-3802	52	26	31	1.10714	12.8

Operation	A	B	C	Log M_{ct}	M_{ct}
S	1,879.0	1,140.0	817.0	86.36821	3,363.0
SS	72,454.0	26,388.0	14,595.0	152.66015	441,659.16
$S^2/50$	70,612.82	25,992.0	13,349.78	149.18935	226,195.38
SSD	1,932.18	396.0	1,254.22	3.47080	215,463.78
σ^2	39.43	8.08	25.41	0.07083	4,397.22
σ	6.28	2.84	5.04	0.26614	66.31
$\bar{S}$	37.58	22.80	16.34	1.72736	67.26
c	0.17	0.12	0.31	0.15	0.99
M_{max}	-	-	-	2.59104 $\longrightarrow$	390.0

3.3.2.1.6 The data from the full design prediction was used to compute the mean down time and the maximum down time. The mean down time is equal to the total down time divided by 50 (sample size) or 67.3 minutes. The maximum down time, computed by the use of equation (3.2), was found to be 390.0 minutes.

3.3.2.2 AN/GRT-3/GRR-7 Communications Equipment - The AN/GRR-7 is a single channel ground UHF receiver which covers the frequency range from 225 to 399.9 mc. It can be used for reception of either voice or tone amplitude modulated signals. The equipment has an average complexity of 325 parts and maintenance is performed at the part level. Power requirements are 140 watts of 115 or 230 volts single phase at 50 to 60 cycles. The equipment will operate satisfactorily at temperatures ranging from -20°F. to +131°F.

3.3.2.2.1 The AN/GRT-3 is a single channel ground UHF transmitter, which covers the frequency range from 225 to 399.9 mc. When used in conjunction with receiver AN/GRR-7 the equipment is capable of establishing two way radio communication with aricraft or other ground communication radio sets. The equipment has an average complexity of 315 parts and maintenance is performed at the part level. Power requirements are 1250 watts of 115 or 230 volts at 50 to 60 cycles. It will operate satisfactorily at temperatures ranging from -20°F. to +131°F.

3.3.2.2.2 Full Design Prediction - AN/GRT-3/GRR-7 - Only a full design prediction was made for the communications equipment. The information on which the prediction is based was obtained from the Air Force technical orders published for this equipment. The steps taken in making the prediction are the same as those for the AN/FPS-6 full design prediction. The results of apportioning the sample to the part classes are shown in Table 3.5, "AN/GRR-7/GRT-3 Failure Distribution." It should be noted that with this equipment the electron tube class was divided into receiving and transmitting types because of the difference in their failure rates. The data derived from the prediction are shown in Table 3.6, "AN/GRR-7/GRT-3 Maintainability Prediction."

TABLE 3.5

AN/GRR-7/GRT-3 FAILURE DISTRIBUTION

Part Class	Symbol	Quan.	Average Part Failures %/1000 Hrs.	No.of Exp. Fail. Per 1000 Hrs.	Contri.To Total Fail. (%)	No. of Fail. for Sample of 50	Actual Failures
Blowers/ Motors	B	2	.189	.378	.003	.156	0
Capacitors	C	239	.010	2.390	.019	.983	1
N-type Diodes	CR	0	-	-	-	-	-
Connectors	J	27	.032	.864	.007	.355	0
Relays	K	5	.359	1.795	.015	.739	1
Coils	L	64	.033	2.112	.017	.869	1
Resistors	R	200	.015	3.000	.025	1.234	1
Switches	S	17	.045	.765	.006	.315	0
Trans- formers	T	25	.133	3.325	.027	1.368	1
Tubes	V	(R)33	1.567	51.711	.426	21.277	21
		(T)13	4.053	52.689	.434	21.679	22
Misc.	-	14	.178	2.492	.021	1.025	1
Total		639	-	121.521	100.000	50.000	49

TABLE 3.6

AN/GRR-7/GRT-3
Maintainability Prediction

Task	Unit	Part	A	B	C	Log M_{ct}	M_{ct}
1	T-282	C618	18	22	17	2.23644	172.4
2	MD-141	K101	44	26	20	1.42833	26.8
3	MD-141	T102	24	22	16	2.09665	124.9
4	MD-141	V101	40	22	20	1.65101	44.8
5	MD-141	V102	40	22	20	1.65101	44.8
6	MD-141	V102	40	22	20	1.65101	44.8
7	MD-141	V103	40	22	20	1.65101	44.8
8	MD-141	V103	40	22	20	1.65101	44.8
9	MD-141	V104	40	22	20	1.65101	44.8
10	MD-141	V103	40	22	20	1.65101	44.8
11	MD-141	V105	42	26	20	1.47857	30.1
12	T-282	Z901	26	22	16	2.04641	111.3
13	T-282	V901	36	28	21	1.55726	36.8
14	T-282	V902	36	28	21	1.55726	36.8
15	T-282	V902	36	28	21	1.55726	36.8
16	T-282	V902	36	28	21	1.55726	36.8
17	T-282	V903	36	28	21	1.55726	36.8
18	T-282	V903	38	28	21	1.50702	32.1
19	T-282	V601	42	26	21	1.46764	29.4
20	T-282	V602	42	26	21	1.46764	29.4
21	T-282	V602	42	26	21	1.46764	29.4
22	T-282	V602	42	26	21	1.46764	29.4
23	T-282	V603	42	26	21	1.46764	29.4
24	T-282	V604	40	26	21	1.51788	33.0
25	T-282	V703	48	28	21	1.25582	18.0
26	T-282	V705	48	28	21	1.25582	18.0
27	T-282	V706	48	28	21	1.25582	18.0
28	T-282	V706	48	28	21	1.25582	18.0
29	MD-141	V301	40	26	20	1.52881	33.8
30	MD-141	V301	40	26	20	1.52881	33.8
31	MD-141	V201	38	28	20	1.51795	33.0
32	MD-141	V202	38	28	20	1.51795	33.0
33	MD-141	V203	48	24	21	1.37802	23.9
34	R-361	L307	28	21	16	2.02672	106.4
35	R-361	R330	32	21	15	1.93717	86.5
36	R-361	V303	34	23	19	1.78211	60.6
37	R-361	V304	54	28	28	1.02859	10.7

TABLE 3.6 (CONT.)

Task	Unit	Part	A	B	C	Log M_{ct}	M_{ct}
38	R-361	V304	39	25	26	1.51890	33.0
39	R-361	V306	44	28	25	1.31238	20.5
40	R-361	V310	34	21	18	1.85414	71.5
41	R-361	V311	28	26	18	1.85211	71.1
42	R-361	V401	26	21	16	2.07696	119.4
43	R-361	V402	26	21	16	2.07696	119.4
44	R-361	V404	26	21	16	2.07696	119.4
45	R-361	V501	35	21	17	1.83995	69.2
46	R-361	V502	35	21	17	1.83995	69.2
47	R-361	V503	53	26	26	1.13667	13.7
48	R-361	V504	35	21	17	1.83995	69.2
49	R-361	V505	36	21	18	1.80390	63.7

Operation	A	B	C	Log M_{ct}	M_{ct}
S	1,863.0	1,206.0	974.0	79.49131	2,508.2
SS	73,513.0	30,068.0	19,708.0	132.48869	188,572.64
$S^2/49$	70,832.02	29,682.37	19,360.73	128.95649	128,389.13
SSD	2,680.98	385.63	347.27	3.53220	60,183.51
σ^2	55.85	8.03	7.23	0.07358	1,253.82
σ	7.47	2.83	2.69	0.27126	35.41
$\bar{S}$	38.02	24.61	19.88	1.62227	51.19
c	0.20	0.11	0.14	.17	.69
M_{max}	-	-	-	2.43341 $\longrightarrow$	271.3

3.3.2.2.3 Maintainability indices were calculated for the communications equipment from the total of the predicted down times. The mean down time value was 51.2 minutes while the maximum down time value was 271.3 minutes.

3.3.3 Field Study - Simultaneous with the predictions of maintainability a program was instituted to observe the actual maintenance performed on the selected equipments at field locations. Observers were trained to monitor maintenance actions, and to gather associated information. Upon completion of their training they were assigned to Air Force sites at Benton AFS, Pennsylvania and Lockport AFS, New York. At these locations the observers recorded down times for actual maintenance tasks and developed checklist scores for each of these tasks. In addition they gathered data concerning the personnel and support parameters.

3.3.3.1 Data Yield - A total of 43 and 23 corrective maintenance tasks were recorded for the AN/GRR-7/GRT-3 and the AN/FPS-6 equipments respectively. Through screening to remove ambiguous data, these totals were reduced to 40 and 22 respectively. At the start of the collection period two operational AN/FPS-6 equipments were located at each site. Midway in the collection program, one AN/FPS-6 at each site was removed and replaced with the AN/FPS-26. Additionally, at the Lockport site difficulty with the primary power circuits curtailed operation for an extended period. These occurrances reduced considerably the potential data yield. Data secured for the AN/GRR-7/GRT-3 generally approached the desired level. Although the overall data yield for the equipments was lower than expected, the sample sizes were considered sufficient to make significant comparisons with the previously predicted values.

3.3.4 Validation Analysis - A detailed analysis of the field data was made and comparisons with the predicted values accomplished. The specific points of comparison were the mean and M_{max}. Prediction equations for the individual equipments were obtained and the results compared to those obtained by the original prediction equation (3.1).

3.3.4.1 Data - Table I-1, "Field Data," (Appendix I) presents the basic data derived from the experiment both for

corrective and preventive maintenance. Table I-2, "Field Data - Phase 5 Maintainability Study," (Appendix I) presents the data utilized for purposes of this analysis. Logarithm of the maintenance time were taken and checklists A, B, and C for corrective maintenance only were used. (For convenience in handling the data, each of the checklists was divided by 100.) Table I-3, "Sum of Squares, Products, etc.," (Appendix I) sets up the data into a form suitable for regression analysis and calculation of simple correlation coefficients. (See Volume 2, Appendix II, "Mathematical Formulas.") The means, variances, standard deviations, and coefficient of variation also were calculated as part of Table I-3.

3.3.4.2 Tests for Normality - Each of the checklists A, B, C, and Z ($Z = \log M_{ct}$) was tested for goodness of fit to the normal distribution, by the Kolmogarov-Smirnov (d) test, at the 5% level. (See Volume 2, Appendix II.) The null hypothosis was: "There is no difference between the distribution of the real data and the normal distribution formed by estimating the mean and the variance of the data." The test values (d) are contained in the following table:

Equipment	N	Test Values (d)
AN/FPS-6	22	0.2819
AN/GRT-3/GRR-7	40	0.2101
Total	62	0.1698

The null hypothesis was upheld in each case tested.

3.3.4.3 Sample Validity - It was necessary before proceeding with the analysis to establish whether or not the new time data were estimates of the same population as the orginal data used in phase four of the study. The table below presents the data utilized in this comparison:

Data	N	$\bar{Z}$	σ_Z^2	σ_Z
Original	101	1.64051	0.21632	0.46510
Total New	62	1.70446	0.17512	0.41847

Since both sets of data were log normally distributed it was decided to apply parametric tests; i.e., the *F* test for similarity of variances and the *t* test for difference of means.

$$F = \sigma_1^2 / \sigma_2^2 \qquad df = (N_1-1),\ (N_2-1) \tag{3.3}$$

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sigma_p \sqrt{1/N_1 + 1/N_2}} \qquad df = N_1 + N_2 - 2 \tag{3.4}$$

Where:

$$\sigma_p = \sqrt{\frac{(N_1-1)\,\sigma_1^2 + (N_2-1)\sigma_2^2}{N_1 + N_2 - 2}} \tag{3.5}$$

The *F* test yielded a value 1.24 and the *t* test a value -0.885 both of which were insignificant at the 5% level. So the statement could be made that the two sets of data were estimates of the same population.

3.3.4.3 New Data Predicted by Nomograph - A check on the reliability of the on-site monitors was provided by predicting the down time from the checklists. Figure 3.1, "New Data Predicted by Nomograph," presents the results of this check. The diagonal lines represent plus or minus two standard errors. It can be seen that all of the points lie inside these two standards.

3.3.4.3.1 Multiple Correlation Coefficients - A further check is provided by inspection of the multiple correlation coefficients. Let the log values determined with the aid of the nomograph be represented Z' and the actual log values be Z; then the multiple correlation coefficients are as follows:

Radar $\qquad r_{zz'} = 0.941 \quad (N = 22)$

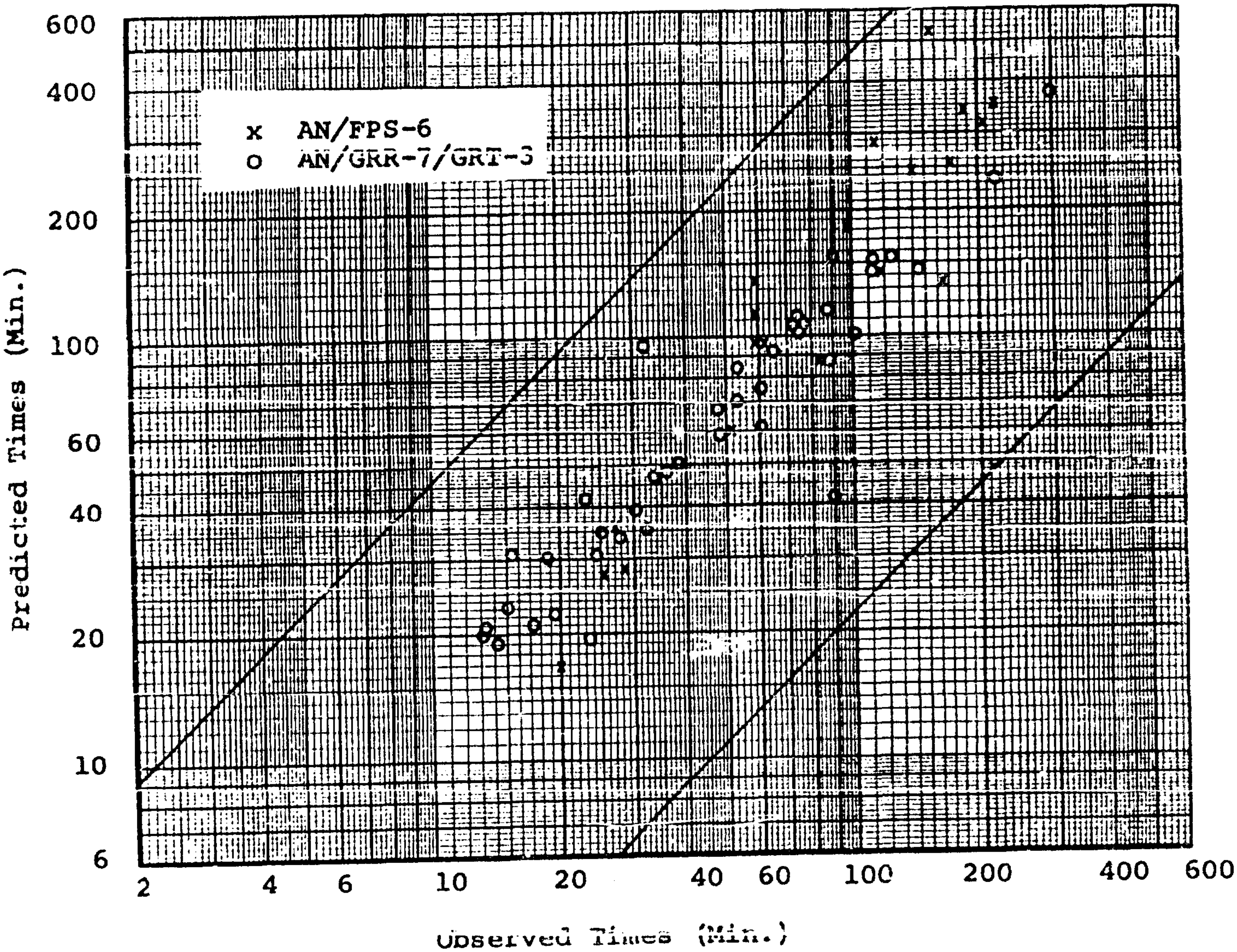

FIGURE 3.1. NEW DATA - PREDICTED BY NOMOGRAPH

Comm. Eq.	$r_{zz}' = 0.941$	(N = 40)
Total	$r_{zz}' = 0.937$	(N = 62)

The null hypothesis was: "That the two samples are not correlated." It can be readily seen that the null hypothesis is disproved and that, in fact, Z and Z' are highly correlated.

3.3.4.4 Prediction vs. Data

The predicted arithmetic mean:

$$\bar{M}_{ct-p} = \sum_{i=1}^{N} M_{ct-i}/N \qquad (3.6)$$

and the predicted maximum downtime:

$$\log M_{max-p} = 1.5 \ \overline{\log M_{ct}} \qquad (3.7)$$

were compared to the actual data for the arithmetic mean:

$$\bar{M}_{ct-d} = \sum_{i=1}^{N} M_{ct-i}/N \qquad (3.8)$$

and M_{max} (95th percentile):

$$\log M_{max-d} = \overline{\log M_{ct}} + 1.65 \ \sigma_{\log M_{ct}} \qquad (3.9)$$

The paragraphs following make these comparisons.

3.3.4.5 Means - The null hypothesis was: "There is no difference between the means of the two samples." The significance level selected was 5% (two tail test.) The statistic chosen was equation (3.4) above. Table 3.7, "Comparison of Means," sums all the pertinent data leading to a value of t, the chosen statistic, and indicates

whether or not t was significant.

3.3.4.5.1 AN/FPS-6 Full Design Prediction - The mean of the full design prediction was verified by the actual data mean. The actual tabled value of t was 2.00. This value would mean that a difference in means of 34.32 minutes would just be significant; and tha actual difference is 26.77 minutes ($t = 1.56$.) The actual difference 26.77 minutes is 28.4% of the observed value of 94.03 minutes and very close to the accuracy figure of 25% that was assumed when this prediction was begun ($N = 50$, $C_x = 1.07$.) (4)

3.3.4.5.2 AN/FPS-6, Preliminary Design Prediction - Table 3.7 reveals that the preliminary design prediction was not verified by the actual data. Normally with a sample of 20 an accuracy of 40% could be expected but the prediction was off by approximately 60% from the actual data. The t value was 3.49 as opposed to a tabulated value of 2.02. There were two major causes for the discrepancy:

a. The predictor in his preliminary prediction has to to assume either of two conditions.

   (1) The maintainability will be controlled (See Section 3, Volume II.)

   (2) That maintainability is not controlled.

   Having made his choice the predictor, guided by his assumption, evaluates the design checklists. The predictor in this case assumed condition (1) on a piece of equipment, the AN/FPS-6, that was not subject to maintainability control; but could not assume otherwise and still maintain his objectivity.

b. It has been found that a sample size of 20 is not large enough. The sample size should be 30 or greater.

3.3.4.5.3 Comparison of the Two AN/FPS-6 Predictions - The means of the two predictions were compared with the results shown in Table 3.7. This question became of

TABLE 3.7

COMPARISON OF MEANS

Equipment	Type of Data	i	N_i	$\bar{X}_i$	σ_i^2	t	Significance
AN/FPS-6	Actual	1	22	94.03	4741.16	1.56	No
	Full Design Prediction	2	50	67.26	4397.22		
	Actual	1	22	94.03	4741.16	3.49	Yes
	Preliminary Prediction	2	20	39.06	229.95		
	Preliminary Prediction	1	20	39.06	229.95	-1.87	Probably
	Full Design Prediction	2	50	67.26	4397.22		
AN/GRT-3/GRR-7	Actual	1	40	63.31	3300.92	1.22	No
	Full Design Prediction	2	49	51.19	1253.82		

interest when the results showed that the preliminary prediction did not match the actual data while the full design prediction did. The tabled t value is 2.00 versus a calculated t value 1.87. The value of the difference would be 30.08 minutes for 5% significance while the actual difference is 28.20 minutes. The probable significant difference of means reflects the fact that one person performed the preliminary prediction and another the full prediction. The one performing the preliminary prediction had to assume condition (1), above, concerning the various maintenance problems, for lack of specific information to the contrary. The other was aware of the true maintenance situation and could assume condition (2).

3.3.4.5.4 <u>AN/GRT-3/GRR-7 - Full Design Prediction</u> - The mean of the full design prediction was verified by the actual data mean. The tabled value of t was 1.99, this value corresponding to a difference in means of 19.78 minutes. The actual difference was 12.12 minutes which was 19.1% of the actual data and well within the accuracy figure of 25%.

3.3.4.6 <u>Maximum Down Time</u> - The null hypothesis used was: "There was no difference between the predicted maximum down time (M_{max}) and tha actual M_{max} obtained from the data." (M_{max} is defined for each case in paragraph 3.3.4.4.) The statistic chosen was the standard error of the 95th percentile. The basic formula for this standard error is as follows: [12]

$$S.E._{(.95)} \cong 2.11 \frac{\sigma}{\sqrt{N}} \tag{3.10}$$

it follows that the standard error of the difference of the log values of M_{max} is given by the following:

$$S.E. \cong 2.11\sqrt{\frac{\sigma^2_{z-1}}{N_1} + \frac{\sigma^2_{z-2}}{N_2}} \tag{3.11}$$

The test criteria were: if the difference exceeded 2 S.E.

it was probably significant and if it exceeded 3 S.E. it was definitely significant. Table 3.8, "Comparison of Log M_{max}," sums all the pertinent data leading to values of the standard error and indicates none of the values were significant. Three comments about the test follow:

a. The approximation sign is used in equation (3.10) above because the formula for standard error assumes a large sample. It is estimated that the maximum error in making this assumption for a small sample ($20 \leq N \leq 100$) is 5%.

b. It is necessary to use the log normal distribution in making the test because the test assumes normality.

c. The test is essentially one sided. That is, it is of no concern if the predicted M_{max} is greater than the actual data M_{max}, e.g. AN/GRT-3/GRR-7. The problem lies in the actual data M_{max} being greater than the predicted value; e.g. AN/FPS-6.

3.3.4.7 Distribution of Down Time - Figure 3.2, "Distribution of Down Time - AN/FPS-6," and Figure 3.3, "Distribution of Down Time - AN/GRT-3/GRR-7," shows the predicted values of down time versus those actually observed. A relatively powerful non-parametric statistical test, "Mann-Whitney, U Test," confirms, in each of the cases, that the predicted and the observed are drawn from the same population. (The preliminary design prediction on the AN/FPS-6 has not been shown because it was demonstrated that it was invalid in preceding sections.) It has been shown that for N_1 greater than 20 [N_1 (Observed), N_2 (Predicted)] the sampling distribution of the test statistic U is that of normal distribution with:

$$\bar{X} = (N_1 \; N_2)/2 \tag{3.12}$$

and

$$\sigma^2 = \frac{N_1 \; N_2 \; (N_1 + N_2 - 1)}{12} \tag{3.13}$$

TABLE 3.8

COMPARISON OF LOG M_{max}

Equipment	Type of Data	i	N_i	Log M_{max_i}	$\sigma_{z_i}^2$	Standard Errors	Signi-ficance
AN/FPS-6	Actual	1	22	2.64615	0.27504	0.22	No
	Full Design Prediction	2	50	2.59104	0.07083		
	Actual	1	22	2.64615	0.27504	1.21	No
	Preliminary Prediction	2	20	2.34963	0.02122		

Equipment	Type of Data	i	N_i	Log M_{max_i}	$\sigma_{z_i}^2$	Standard Errors	Signi-ficance
AN/GRT-3/GRR-7	Actual	1	40	2.22904	0.11717	-1.46	No
	Full Design Prediction	2	49	2.43341	0.07358		

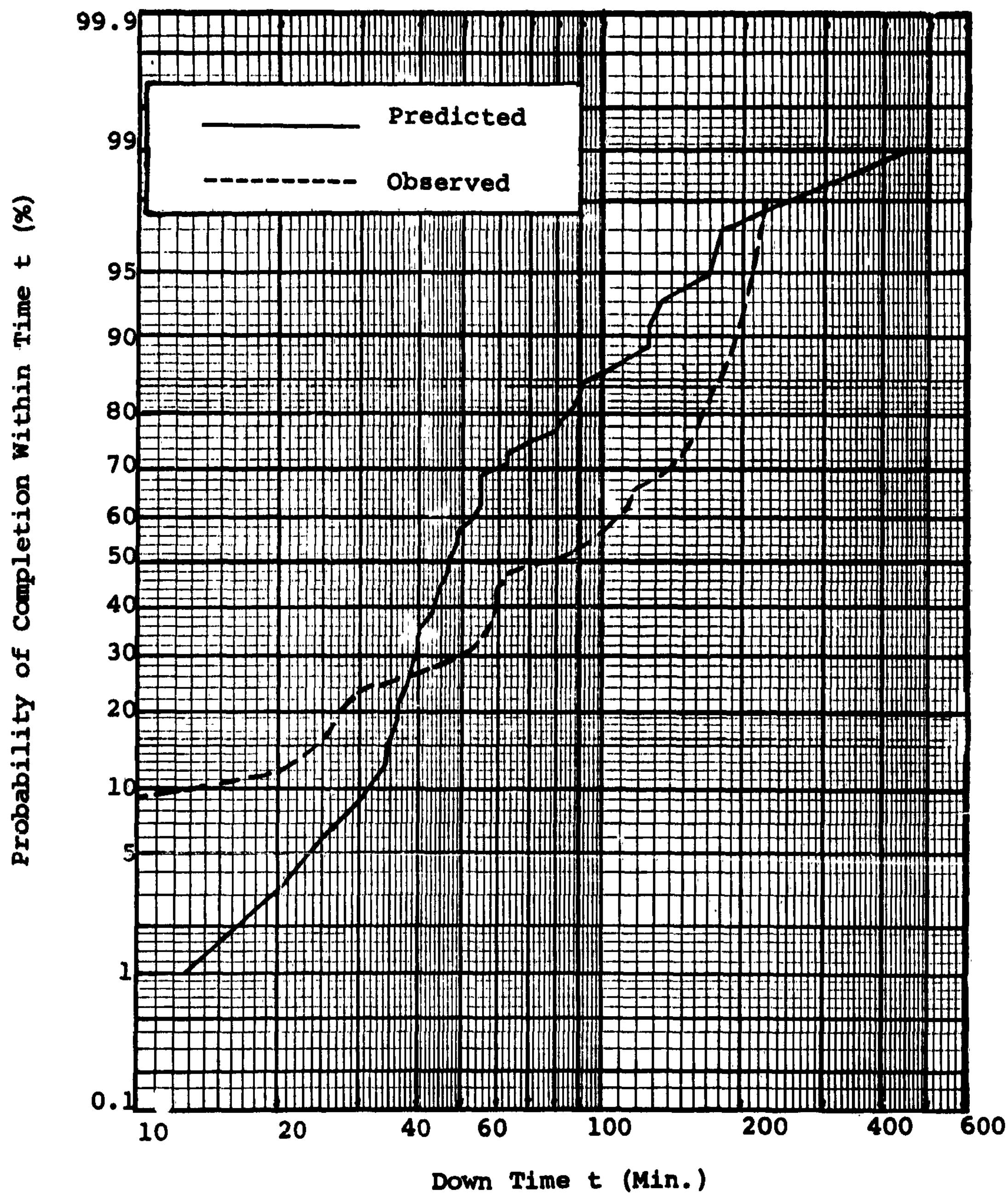

FIGURE 3.2. DISTRIBUTION OF DOWN TIME-AN/FPS-6

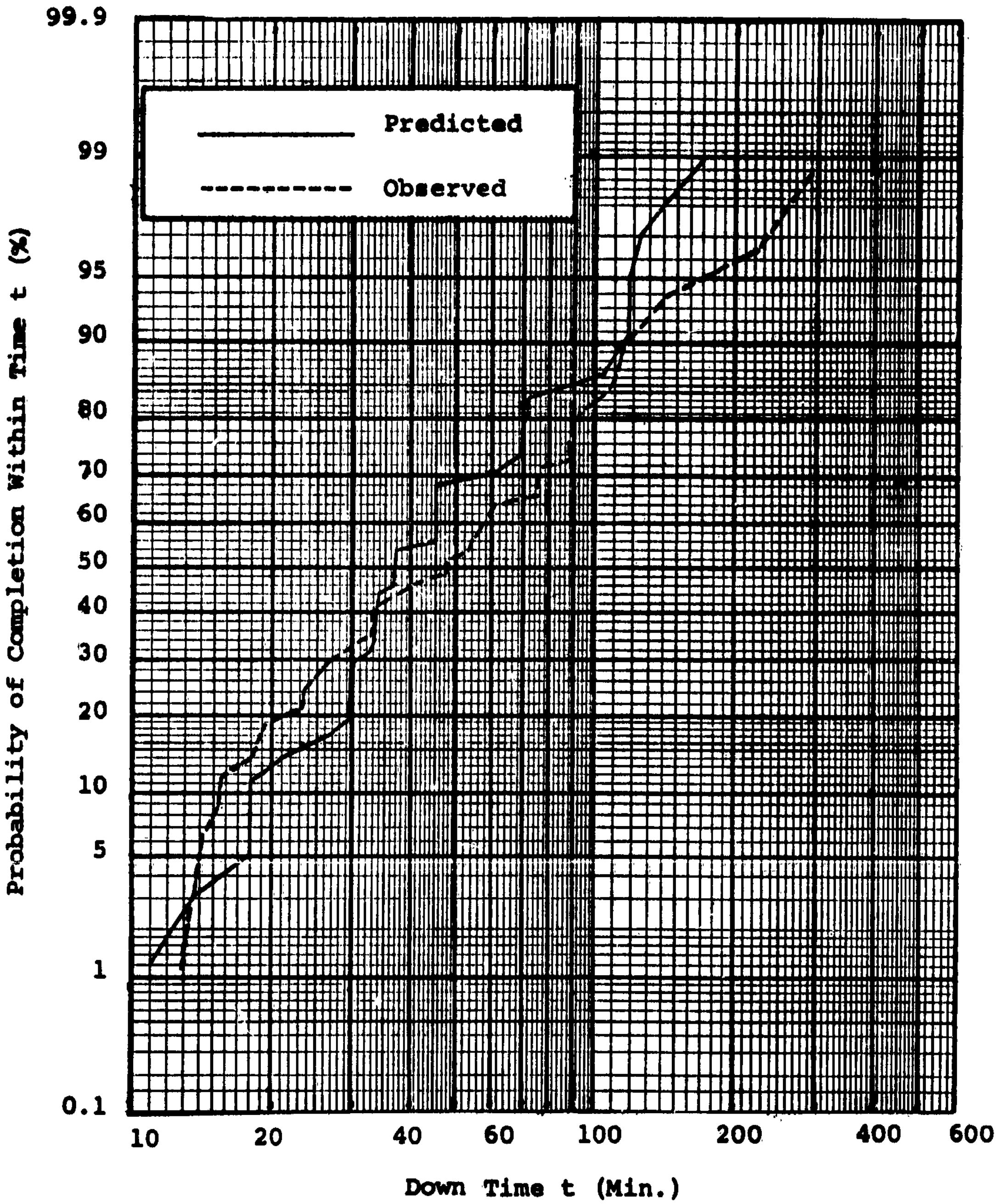

FIGURE 3.3. DISTRIBUTION OF DOWN TIME-AN/GRT-3/GRR-7

with the test statistic observed in Z values as follows:[11]

$$Z = \frac{U - \bar{X}}{\sigma} \tag{3.14}$$

The cases cited above Z equals -1.70 for the AN/FPS-6 and Z equals -0.29 for the AN/GRT-3/GRR-7; inside the 5% tabled value of ± 1.96. The computation of U involves ranking of both sets of data intermingled, adding the ranks of the smaller of the two pieces of data and obtaining a value which is called R_1, [11] then applying the formula as follows:

$$U = N_1 N_2 + \frac{N_1 (N_1 + 1)}{2} - R_1 \tag{3.15}$$

For a further explanation of the Mann-Whitney Test see Appendix II, Volume II.

3.3.4.8 <u>Internal Consistency</u> - Internal consistency means how the checklist scores compare with the time data (log transform) when a regression equation is formed for each of the new equipments. The data used for forming the equation were the 22 tasks on the AN/FPS-6 and the 40 tasks on the AN/GRR-7/GRT-3. The purpose in doing this is to check internally the relative magnitude of the constants and multipliers of the new equations compared to that of the equation on which the prediction was based (Equation 3.1).

3.3.4.8.1 <u>AN/FPS-6</u> - The simple correlation coefficients were as listed below:

		A	B	C	Z
A		1	0.663	0.790	-0.925
B	N = 22 df = 20		1	0.549	-0.692
C	5% = 0.423			1	-0.858
Z					1

All of the coefficients were significant to the 5% level.[9]

3.3.4.8.2 When the correlation coefficients were analyzed by partial correlation techniques the results were as shown below: (For a summary of the technique used see Appendix 2, Volume 2, this report.)

		A	B	C	Z
A		-	0.076	-0.007	-0.722
B	N = 22 df = 18		-	-0.125	-0.303
C	5% = 0.444			-	-0.553
Z					-

Two of these coefficients were significant to the 5% level. These were AZ and CZ. Checklist A - Design Factors, was again independent of the other two checklists B and C.[4] Likewise B and C were independent of each other. Even though B was not significantly correlated with log time it was decided, in the interests of uniformity, to develop a regression equation using all three checklists (A, B, and C) and log time (Z).

3.3.4.8.3 The regression equation developed was:

$$Z_R = \log M_{ct-R} = 3.18691 - 0.02320\ A - 0.01349\ B - 0.02120\ C \qquad (3.16)$$

with a multiple correlation coefficient of:

0.953

and a standard error of:

0.17208 log minutes

The regression coefficients of A and C were tested, by the *t* test, at the 5% level and were significant; that of B was

significant at the 10% level. Figure 3.4, "Radar Data - Observed vs. Predicted," shows the individual task time. The outer pair of diagonal lines represents two standard errors from the old data used to develop the nomograph. The inner pair represents two standard errors which bound only the new equation.

3.3.4.8.4 AN/GRR-7/GRT-3 - Using the same analysis procedure as in paragraph 3.3.4.8.1, the simple correlation coefficients were as listed below:

		A	B	C	Z
A		1	0.382	0.616	-.812
B	N = 40 df = 38		1	0.564	-.703
C	5% = 0.312			1	-.850
Z					1

All of the coefficients again were significant at the 5% level.

3.3.4.8.5 Partial correlation techniques yielded the following results:

		A	B	C	Z
A		-	-0.533	-0.372	-0.809
B	N = 40 df = 36		-	-0.271	-0.687
C	5% = 0.320			-	-0.724
Z					-

The intercorrelations are such that a procedure similar to Section 2.3.2, "Comparison of Deviations," in the Phase 4

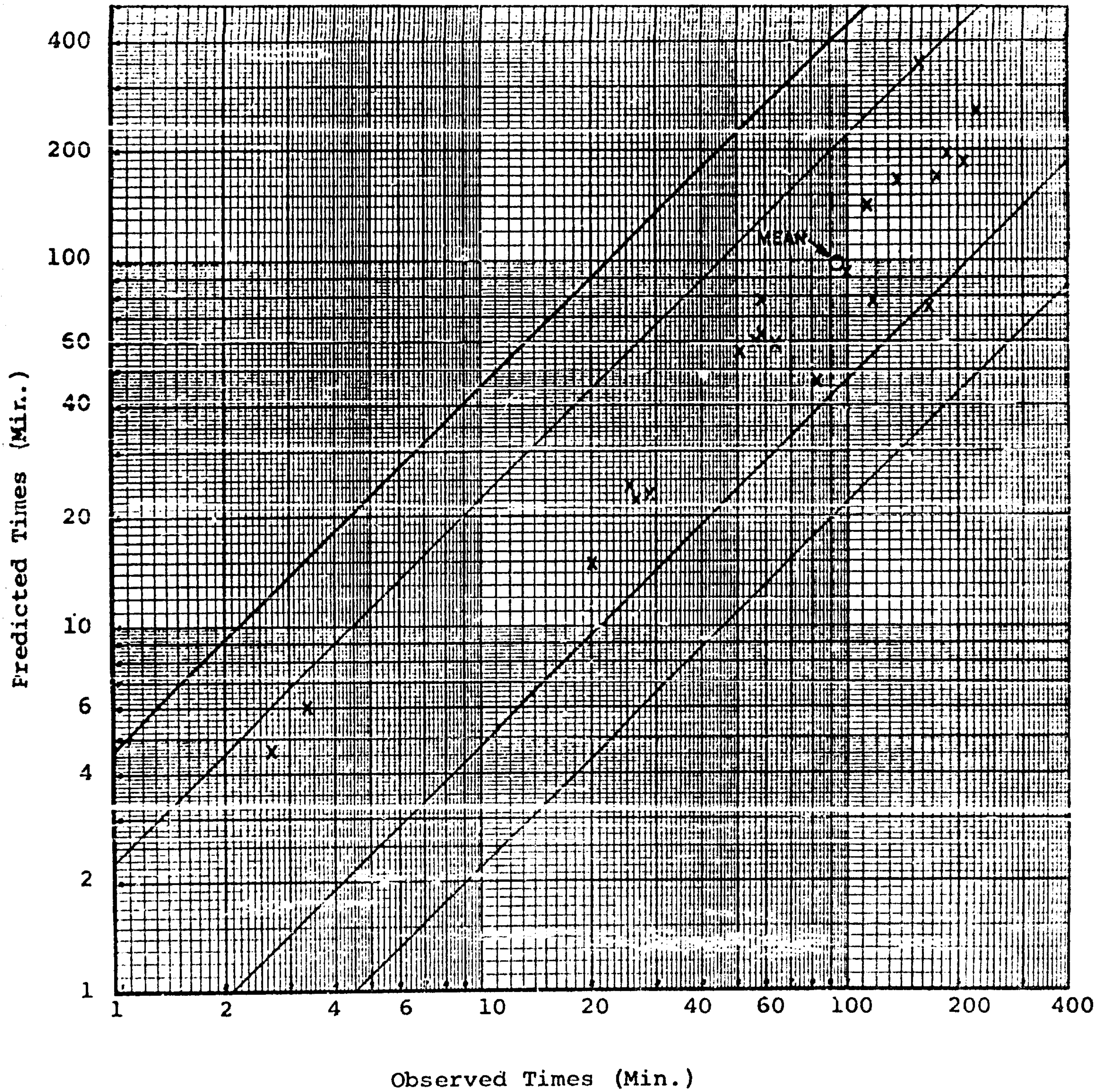

FIGURE 3.4. RADAR DATA-PREDICTED vs. OBSERVED

report, had to be adopted; i.e. by testing the comparative predictive power for various combinations of A, B, and C. The combination A, B, and C had least residue (0.07013), was the best predictor and, more importantly, was significantly better than any other combination or single variable when used as a predictor.

3.3.4.8.6 The regression equation developed was:

$$Z_c = \log M_{ct-c} = 3.44326 - 0.02142\,A - 0.02335\,B - 0.02170\,C \qquad (3.17)$$

with a multiple correlation coefficient of:

0.964

and standard error of:

0.09580 log minutes

The regression coefficients of A, B, and C were tested, by the _t_ test, at the 5% level and were significant. Figure 3.5, "Communications Equipment Data - Observed vs. Predicted," shows the individual task times. The outer pair of diagonal lines represents the two standard errors inherent in using the nomograph. The inner pair represents the two standards errors in using the new equation.

3.3.5 <u>Summary</u> - The full design predictions made were successful in that they correlated with the data gathered from the field. Comparison of the means, M_{max}, and the distributions as a whole were uniformly successful in each case when comparison was made between the predicted data and the data collected in the field. The equations developed for each equipment from the field data, compared quite well with equation (3.1) on which the predictions were based. The preliminary prediction on the AN/FPS-6 failed to correlate with the field data. Possible reasons are cited in paragraph 3.3.4.5.2.

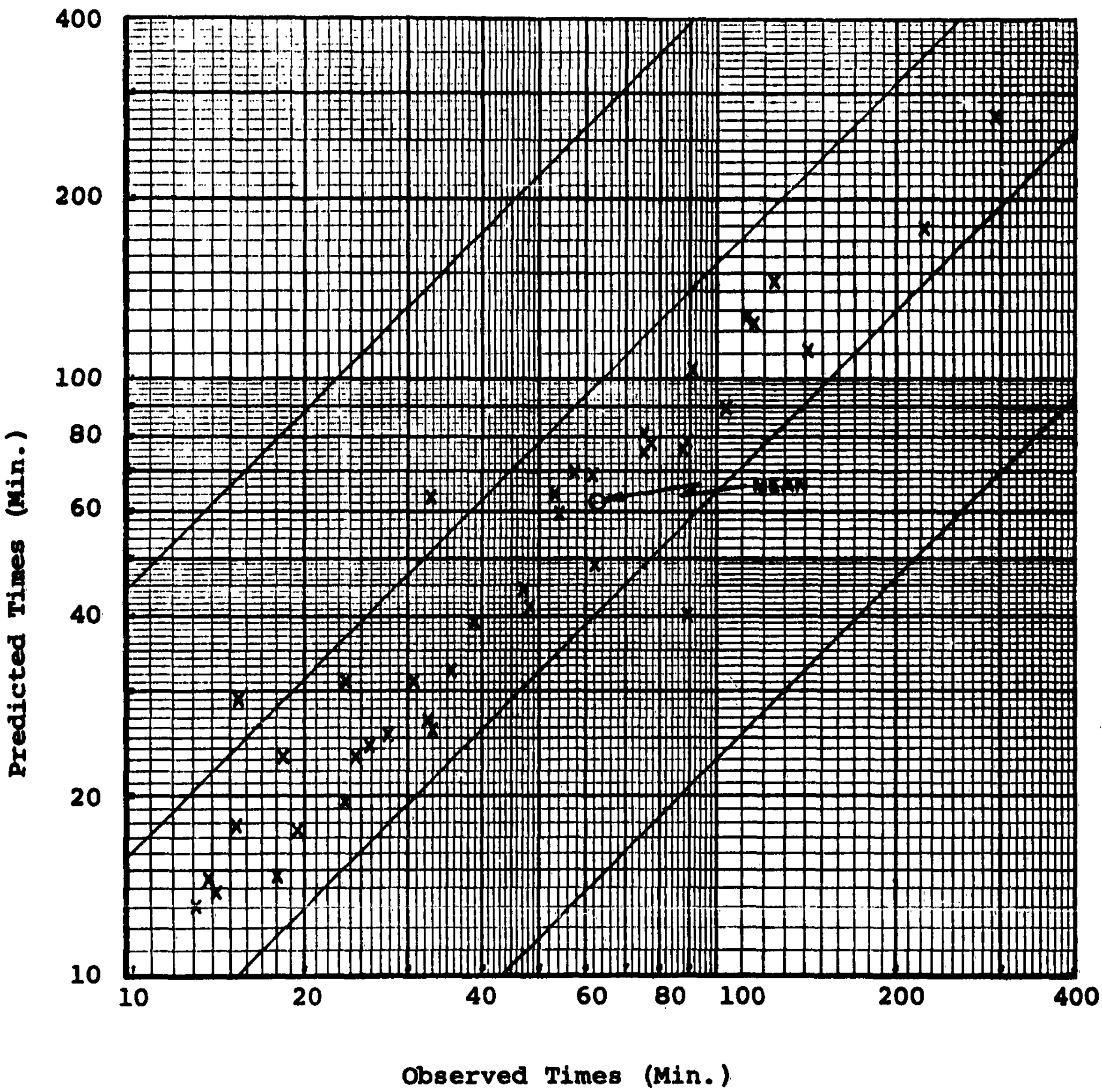

FIGURE 3.5. COMMUNICATIONS EQUIPMENT DATA-PREDICTED vs. OBSERVED

3.4 Electronic Maintenance Proficiency Test

The prime objective of this program is to demonstrate a predictable relation between the Electronic Maintenance Proficiency Test (EMPT), developed under Contract AF30(602)-2057, and maintenance (repair) time. Additionally, the program seeks to establish the existence of maintenance skills and identify them. Through the identification of maintenance skills and the ability to relate such skills to the time criteria, it would be possible to equate the maintenance performance of different technician classes. Specifically, the ability to relate the performance of a contractor technician to that of an Air Force technician would be most valuable during maintainability specification demonstration.

3.4.1 Background - Development of the EMPT stemmed from an attempt to quantify the human element in the maintenance process. The test is comprised of ten subgroups designed to evaluate a maintenance technician's mental and motor skills. In general, the emphasis in the EMPT is on understanding, rather than on rote memory of facts. Although some of the subtests require the recalling of facts, they do not form a major part of the EMPT, where used, they are considered as an attempt to include items that should be generally known to an experienced technician.

3.4.1.1 Test Construction - Test construction followed the general format of the well known Wechsler Adult Intelligence Scale. Construction steps included:

a. Item construction

b. Item review

c. Editing

d. Preliminary tryout

e. Pretesting

f. Test analysis

g. Item analysis

h. Item selection

i. Item ordering

j. Final revision

k. Test scoring reliability

Completion of these steps led to qualification trial performed at Keesler Air Training Command. The trial employed students and instructor personnel drawn from the training center. Criterion for the validation was time to repair six selected maintenance tasks from the AN/FST-2, Data Coordinate Transmitting Equipment.

3.4.1.1.1 Analysis of data derived from this program revealed that no correlation could be established between the criterion (repair time) and the observed EMPT scores (total or subgroups). This difficulty was believed to be possibly attributable to the following:

a. The varying degree of specific equipment experience possessed by the test subject resulted in an unexplainable variance.

b. Criterior tasks drawn from the AN/FST-2 equipment did not represent a sufficient range of maintenance skill requirements.

c. Reliability of repair time remains suspect as to its use as a qualifying criteria.

3.4.1.1.2 In an effort to secure resolution to these problem areas, the program set forth in the following discussion was established.

3.4.2 Validation Program - The validation program followed was a two step study. The initial test phase was designed primarily to assess the reliability of maintenance performance and the resultant time criterion. Here a single task was administered to a group of forty technicians on a test - retest basis. Correlation of the test - retest data provided a basis for the reliability evaluation of the criterion. The final test phase incorporated into the test sequence five additional tasks, which provided data for correlation with the EMPT scores. The second phase was limited to the twenty-five technicians possessing the higher test - retest relationships during phase I.

3.4.2.1 Program Development - The basic objective of the initial testing phase was to establish the reliability of maintenance time and justify its use as a criterion for measurement of technician performance. The reliability if proven would provide a sound basis on which to proceed toward the validation of the Electronics Maintenance Proficiency Test (EMPT) as a predictor of technician performance. A further objective of the initial phase was to identify a range of discernable maintenance skills. These skills when related to specific maintenance tasks will provide a means of selecting a group of representative tasks. Use of this task group in the formal validation program will assure that all important skills are employed. The following discussion presents the skills and tasks selected and an associated description of the techniques employed.

3.4.2.2 Skill Selection - The identification of maintenance skills was approached by reviewing the maintenance process. For the identification procedure a skill was defined as: a developed or acquired ability to perform a particular act. With this context in mind the examination of the maintenance process led to the establishment of the following general skills:

a. Testing and measuring - Testing and measuring refers to the mental and physical acts of securing equipment status information through the use of test equipment.

   Example: Observe a waveshape on an oscilloscope and obtain the maximum and minumum values of the wave.

b. Verbal - Verbal skill refers to the ability to carry out oral instructions and includes understanding of the jargon and abbreviations used in electronics.

   Example: You are told to measure the MDS and SWR of a system.

c. Written comprehension - This skill refers to the ability to understand technical orders and schematics, fill out forms, make out reports, etc.

   Example: Tracing the AVC circuit on a schematic and noting possible sources of trouble.

d. Electrical manipulative - The actions performed on electrical, electronic, and electro-mechanical circuits.

   Example: Soldering a resistor to two terminals.

e. Mechanical manipulation - The action performed on mechanical items.

   Example: Dismantling a clutch used in a radar antenna.

f. Electronic - The ability to apply knowledge of the electronic functioning and the physical characteristics of equipments, components, circuits, and parts.

g. Logic - The ability to solve problems logically with respect to components within equipment, circuits within component, and parts within circuit.

h. Safety - The ability to perform maintenance in a safe manner.

It was the opinion of the engineers concerned with the study that the skills listed were present in all maintenance tasks to varying degrees. To ascertain the degree, on the basis of engineering judgment, did not appear to be within

the realm of technical feasibility. Rather, it was felt that such division could only be made from an analysis of data developed expressly for this purpose.

3.4.2.2.1 As stated, the eight skills listed appear in all tasks but it was noted that these skills may differ widely depending upon the level at which maintenance is performed. Specifically, maintenance performed on electronic devices may be performed at the system, equipment, component, circuit, and part levels. A technician in performing a task may work solely at one level or traverse the total complement. The ability to perform at one level certainly does not assure satisfactory performance at the others. For example, a technician skilled in performing maintenance at the equipment level (isolating and replacing black boxes) may be completely incapable, without additional training and experience, of working effectively at either the system or the component level.

3.4.2.2.2 On this basis, it was felt that the general skills take on unique characteristics at different levels of application. Since these levels are readily discernible it was recommended that tasks be developed reflecting the various maintenance levels and associated skills. Specifically, tasks were developed to reflect the general skills associated with the following levels:

a. Equipment -
b. Component -
c. Circuit -
d. Part -

General Skills 1 through 8

The validation program permits determining analytically if significant differences exist between the four specific skill areas. Knowledge of such difference will be of significant value in guiding the design of future equipments.

3.4.2.3 <u>Task Selection</u> - For the validation program the RCA Electronic Trainer Model 121 was used to form the equipment on which maintenance was performed. This choice was predicated on the inherent flexibility of this device, which

is achieved by the use of plug-in assemblies at both the circuit and part levels.

3.4.2.3.1 Equipment Selection - The electronic trainer offered a choice of seven basic equipment types which may be constructed from the circuits provided. These include:

a. Audio Amplifier

b. Superheterodyne Receiver

c. Radar System

d. Radar Timing Equipment

e. Marker Indicator Equipment

f. Range-Notch Equipment

g. Pulsed Radar Equipment

The superheterodyne receiver and marker indicator equipments were chosen for the experimental procedure because they: (1) represent analog and digital equipment respectively, (2) are relatively sophisticated in performance and construction, and (3) offered suitable operational stability for a long term experiment.

3.4.2.3.2 Task Identification - For the selected equipments a total of 229 tasks were identified and related to the basic parts. Table 3.9, "Marker Indicator Tasks (Partial)," presents a partial listing of the tasks identified. Here, the tasks are listed with a numerical identification of the mode of failure at the part, circuit, component and equipment level. Table 3.10, "Failure Mode Identification," identifies the failure codes employed. The failure mode analysis contained on Table 3.9 is used in the task selection as a guide to secure a range of frequently occurring malfunction symptoms.

3.4.2.3.3 Selection Plan - In accordance with the postulate that discreet maintenance skills exist for maintenance performed at the equipment, component, circuit, and part

TABLE 3.9

MARKER INDICATOR TASKS (Partial)

No.	Task	Failure Modes: Part	Circuit	Component	Equipment
1	R5201	1	1	1	1
2	C5201	2	1	1	1
3	V5201	3	1	1	1
4	V5201	4	1	1	1
5	V5201	5	1	1	1
6	R5204	1	1	1	1
7	C5204	2	1	1	1
8	R5205	1	1	1	1
9	C5205	2	2	3	2
10	C5205	1	1	1	1
11	R6401	1	3	3	3
12	R6402	1	1	1	1
13	V6401	3	4	4	4
14	V6401	4	1	1	1
15	V6401	5	1	1	1
16	C6401	2	5	5	27
17	R6403	1	1	1	1
18	R6404	1	5	5	27
19	R6405	1	1	1	1
20	C6402	2	2	2	4
21	C6402	1	1	1	1
22	R7301	1	3	9	5
23	V7301	3	4	4	6
24	V7301	4	1	1	7
25	V7301	5	1	1	7
26	R7302	1	1	1	7
27	C7301	1	3	1	7
28	S7301	6	1	1	7
29	C7302	2	5	4	6
30	C7302	1	5	6	27
31	L7301	1	1	1	7
32	C7303	2	2	1	7
33	C7303	1	1	1	7
34	R7801	1	1	1	7
35	V7801	3	4	4	6
36	V7801	4	1	1	7
37	V7801	5	1	1	7
38	C7801	2	4	4	6
39	R7803	1	1	1	7
40	R7804	1	1	1	7
41	C7802	3	2	3	8
42	C7802	1	1	1	7
43	R8301	1	6	6	27
44	V8301	7	4	4	6
45	V8301	4	1	1	7

TABLE 3.10

FAILURE MODE IDENTIFICATION

Parts

1. Open
2. Shorted
3. Low Transconductance
4. Open Filament
5. Grid to Cathode Short
6. No Contact
7. Low Emission
8. Plate to Cathode Short
9. Air Leak
10. Grid to Grid Short
11. Grounded Terminal

Circuits & Components

1. No Output
2. B+ on Output
3. Incorrect or Wrong Waveshape
4. Weak or Low Output
5. Changed Waveshape
6. None
7. Wrong Frequency & Waveshape
8. Phase Shifted Output
9. Increased Intensity
10. Wrong Frequency
11. Weak Distorted Output
12. Oscillation
13. Distorted Output
14. Normal Output No AVC

Equipment

1. Long Sweep and No Marks
2. Long Free Running Sweep & No Marks
3. Jittery Display
4. Long Sweep & Jittery Marks
5. Increased Mark Amlitude
6. Decreased Mark Amlitude
7. No Marks
8. Negative & Positive Marks
9. Short Sweep with Two Marks
10. Long Unstable Sweep
11. Short Unstable Sweep
12. Unstable Sweep
13. No Sweep
14. Long Invisible Sweep
15. Sweep Shifted Right
16. No CRT Display
17. Display Out of Focus
18. Increased Intensity
19. Sweep Low Left & Intensity
20. Sweep Low
21. Sweep Left
22. Short Sweep & Short Mark
23. Spot on Scope
24. Long Sweep with Ripples
25. Change in Mark Pos.
26. Weak Unstable Sweep
27. None
28. Reduced or Weak Output
29. No Output
30. Weak Distorted Output
31. No AVC
32. Oscillation

levels, the selection plan calls for equal samples (tasks) to be established for each level. Table 3.11, "Task Selection Format," illustrates the format to be used. It will be noted that three tasks are established for each equipment and these are comprised of one task at each level. Task selection is accomplished by determining and selecting parts, circuits, and components associated with the most frequently occurring modes of failure for the two equipments. Assignment of a particular mode to a specific maintenance level is accomplished by random selection. Task administration sequence is also determined through the random process.

3.4.2.3.4 Selection Results - Table 3.12, "Marker Indicator Failure Modes," presents the results of analyzing the failure modes of the Marker Indicator. Here the most frequently occurring modes have been related to the component and circuits of this equipment. The three circled entries indicate the modes and the associated component and circuits to be utilized for this equipment. Note that there is a tie between modes 10 and 11 and each involves 12 occurrences. An investigation of the reliability rates of the parts involved indicated that mode 10 would occur more frequently.

3.4.2.3.5 A similar analysis was made for the receiver and the results are presented in Table 3.13, "Receiver Failure Modes," the circled entries indicate the choices made. A slight departure from the established routine was made here in assigning mode 29 to the detector circuit of the 2nd detector component in lieu of the 1st detector. This choice was made since mode 28 so clearly related to the 1st detector component, and the chosen assignment provided a better task balance within the receiver.

3.4.2.3.6 Random selection process was used to relate the chosen failure modes to the maintenance levels and the task sequence. Table 3.14, "Selected Tasks," presents the results of this selection. In the case of the component and circuit task the failure mode analysis dictated the specific area chosen. For the part task random selection was used to designate the actual part indicated.

3.4.2.3.7 Table 3.15, "Task Introduction Method," identifies

TABLE 3.11

TASK SELECTION FORMAT

		Equipment			
		Superheterodyne Receiver		Marker-Indicator	
Skill Level	Technicians	Test	Retest	Test	Retest
Component	1 2 3 . 25	(Task Time)			
Circuit	1 2 3 . 25				
Part	1 2 3 . 25				

TABLE 3.12

MARKER INDICATOR FAILURE MODES

	Master Trigger		Mark Generator			Sweep Generator				Cath. Ray Ind.	Power Supply	
Equip. Mode	RC Osc.	Tri. Lim.	Peak. Osc.	Mix. Amp.	Diode Lim.	Step Count.	Blocking Osc.	Sawtooth Gen.	Bias Supply	CRT	Power Supply	Voltage Trip.
1	9	6										
7			8	6	3							
10						4	8					
11						1	1	2	8			
16										1	2	7
23											6	

TABLE 3.13

RECEIVER FAILURE MODES

	1st Detector		2nd Detector		Power Supply	Audio Amplifier		
Mode	RF Amp.	RF Conv.	IF Amp.	AVC Det.	Power Supply	AF Amp.	Phase Splitter	Power Amp.
29	1	14	5	6	8	6		4
28	10	1	1	3	1	1	3	
30	2		2		1		5	
31	2	2		3				

TABLE 3.14

SELECTED TASKS

	Equipment					
	Marker Indicator			Superheterodyne Receiver		
Task	Comp.	Circuit	Part	Comp.	Circuit	Part
1						Resistor R2103
2	Sweep Gen.					
3				2nd Det.		
4		Peak. Osc.				
5					Phase Splitter	
6			Tube V5201			

TABLE 3.15

TASK INTRODUCTION METHOD

Task	Method	Symptom
1	Open R2103	Weak Output
2	Open R7101	Long Unstable Sweep
3	Open R2701	No Output
4	Open C7303	No Range Marks
5	Short C2902	Distorted Output
6	Grid to Cath. Short	Long Sweep and No Marks

the specific part manipulation methods necessary to achieve the failure modes associated with the component and circuit tasks. Additionally, it identifies the failure mode for the two part tasks. All selected tasks were operationally verified to assure that the stated mode of failure would produce the desired result.

3.4.3 Initial Test Phase - The electronic technicians used for the experimental procedure were drawn from the engineering support staff of the RCA plant at Burlington, Massachusetts. These personnel may be considered typical of those who would be utilized in maintainability demonstration testing as called out in current specifications. The test sample was drawn from personnel classified into the following three job descriptions:

a. Laboratory Technician - Responsible for fabricating proposed circuit designs under close engineering supervision. Also, responsible for tests completed on electronic systems during manufacturing phase.

b. Senior Laboratory Technician - Duties identical to laboratory technician but requires less direct supervision.

c. Engineering Technician - Works closely with design engineers preparing circuit breadboards of newly designed circuits and tests new devices to ascertain operational parameters. Works with minimal supervision.

3.4.3.1 The principal criterion used to select technicians were; (1) capability of performing assigned task and (2) availability for entire test period. The distribution by classes of the forty technicians selected were as follows:

Laboratory Technician	5
Senior Laboratory Technician	21
Engineering Technician	14
	40

It was originally intended to draw nearly equal samples from each of the three groups but it was found that several the lesser skilled laboratory technicians were unable to complete the task. Those failing were replaced with technicians from the higher categories to achieve the full test group. Additionally, the requirement for availability during the entire duration of the test program influenced the sample distribution to some degree. Table II-1, "Biographical Data," (Appendix II) reviews the pertinent data for each technician selected.

3.4.3.2 The technicians used in the test procedure had no previous experience on the particular type of equipment selected. To provide the appropriate background a standardized training session, explaining the operation and maintenance procedures for the equipment, was given to each technician.

3.4.3.3 Task Administration Procedure - Considerable attention was devoted to standardizing the test environment, test equipment status, and equipment condition for each task administration. Figure 3.6, "Equipment Arrangement," illustrated the layout utilized for the experiment. Prior to the start of each test, the equipment was placed in the position shown. Additionally, the following pretest checks were made:

3.4.3.3.1 Equipment Status at Start of Each Task Administration.

a. RCA 121 Trainer

   Equipment operated and its operation completely verified and optimized. Subject fault part installed and symptoms of failure verified. Power switch and B+ switches positioned at "ON".

b. VOM

   Physically placed immediately to the left of the trainer. Selector switch positioned at "1000V". Range switch positioned at "DC". Test leads (red & black) inserted in meter.

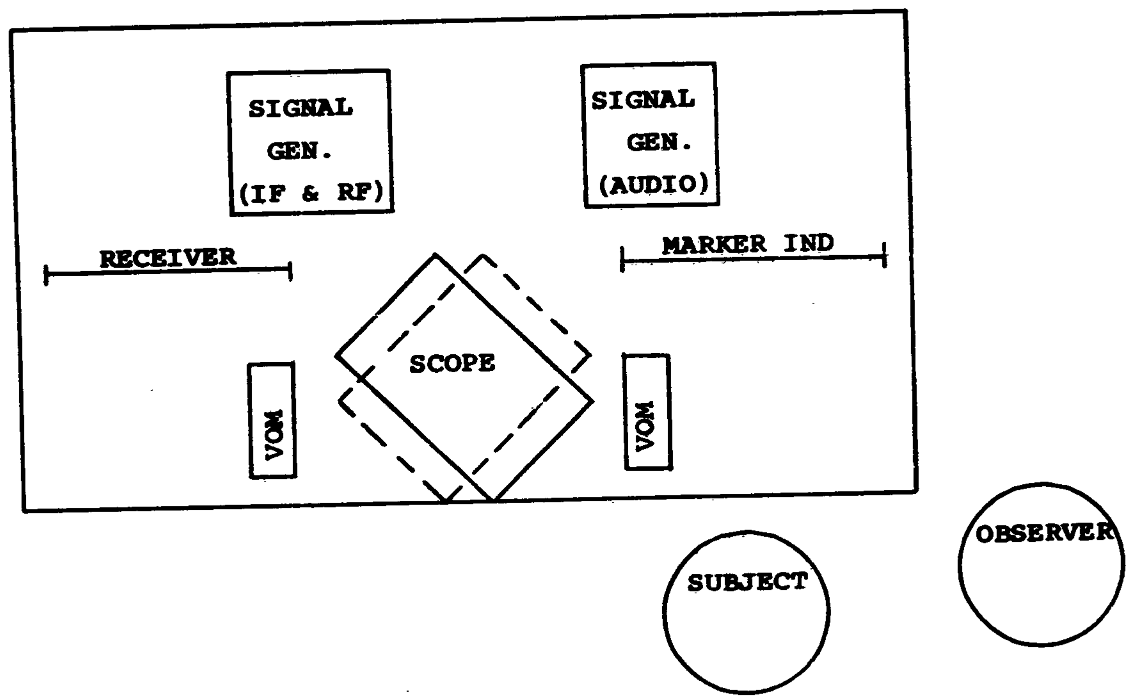

FIGURE 3.6. EQUIPMENT ARRANGEMENT

c. Oscilloscope

Physically placed immediately to the left of the VOM and positioned to face subject when standing in front of trainer. Volts per CM Selector positioned at "20". Time per CM Selector positioned at "0.5" msec/CM. Sync. Selector positioned at "Auto". Oscilloscope ground externally connected to trainer unit. Power switch positioned at "ON".

d. Signal Generator

Physically placed to the left and to the rear of the VOM. No leads connected.

In addition to the actions outlined above, all test equipment was calibrated prior to the initial testing and proper operation continuously verified throughout the study.

3.4.3.3.2 The observers utilized in the experimental procedure were personnel experienced with data collection techniques and were thoroughly familiar with all aspects of testing procedure. Prior to the start of the actual testing, several dry runs were accomplished to assure that all administration details had been established.

3.4.3.3.3 Supplementary to this procedure, the following verbal introduction of the subject to the task was employed.

a. "Our task is concerned with the...(Superheterodyne receiver/Marker Indicator.)

b. The failure is at the...(part, circuit, component) level. (Due to confusion surrounding the word "Component" a description of a part, circuit, and component is given.)

c. There is only one failure and we want you to locate it to the responsible...(part, circuit, component.)

d. You may have a...(part, circuit, component) replaced any time you wish by asking for it.

e. Any time a part is replaced or some corrective action is taken we want you to verify the replacement action."

Through the attention given to procedure detail, it is felt that variance due to extraneous factors has been reduced to a minimum. The data resulting from this experiment should be almost totally a function of the individual technician proficiency.

3.4.3.4 Data Analysis - The time data (test-retest) are presented in Tables II-2 and II-3 (Appendix II) respectively. In addition to the total time, the tables present the composition of total time in terms of the five designated elements. Figure 3.7, "Time Element Distribution," presents a comparison of percentage distribution for test and retest against the previously observed field data. It will be noted that for the selected task a marked similarity exists between the test-retest measurements. Additionally, a good relationship exists with the previously collected field data.

3.4.3.4.1 Figure 3.8, "Test-RetestCorrelation (40)," presents the analysis made to determine the correlation (reliability) for the full test data. The calculated r was found to be 0.12 (5% level 0.31). This calculation was made by using the logarithm of the time data and grouped analysis method. The columns marked f indicate the frequency of each cell interval and portrays the general form of the underlying distribution. The test data has transformed generally to the normal configuration while the retest remains skewed to some extent. The calculated coefficients of variation indicate that the log-normal distribution may be used for the analysis.

3.4.3.4.2 Figure 3.9, "Test-Retest Correlation (25)," presents the analysis of the time data for 25 selected subjects. The selection was made by including those subjects which lay along the bisecting line of the angle formed by the test-retest orthogonal normalized scales. This technique permits selecting subjects who possess not only good test-retest relationships but additionally,

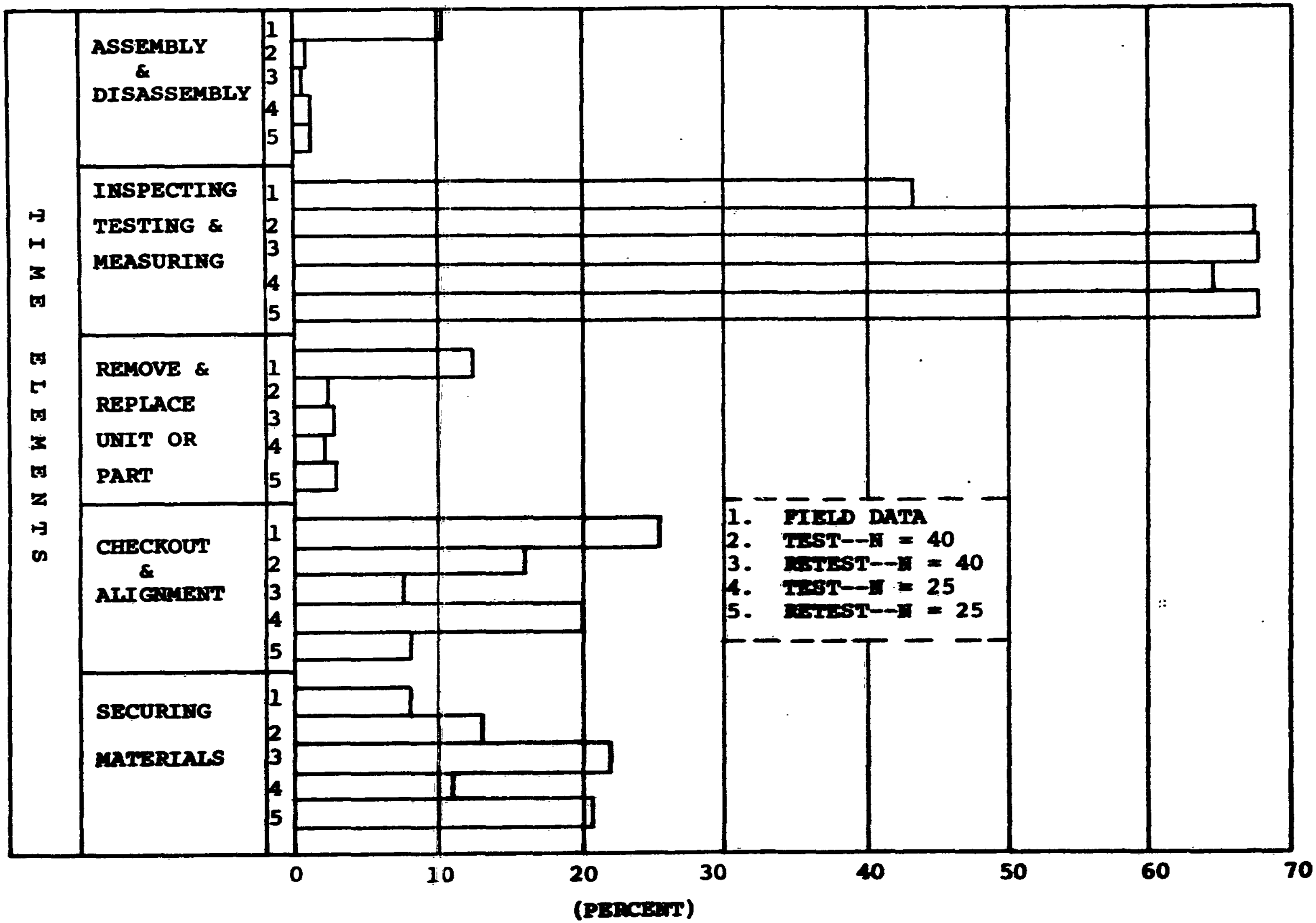

FIGURE 3.7. TIME ELEMENT DISTRIBUTION

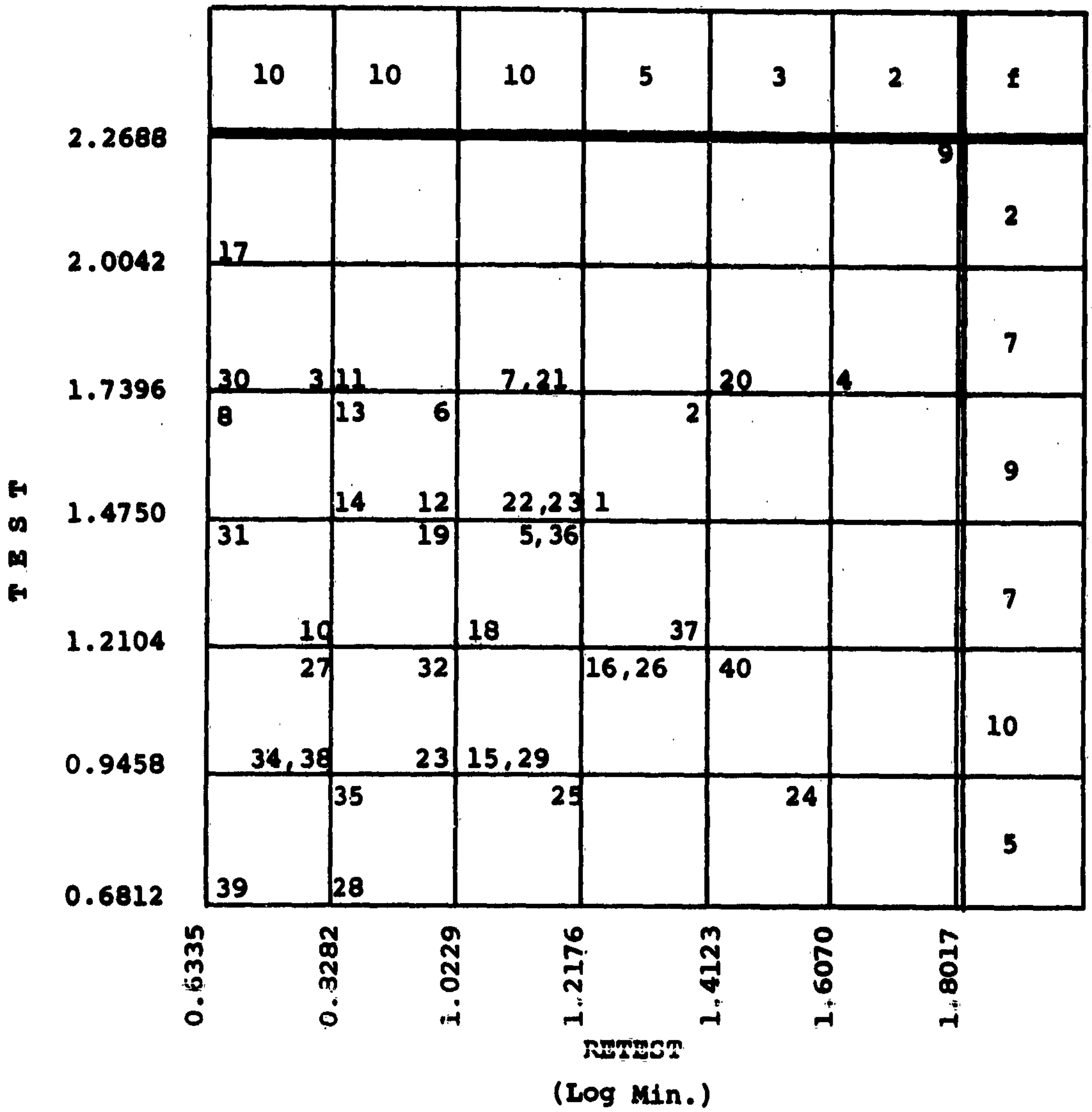

FIGURE 3.8. TEST-RETEST CORRELATION

(N = 40, r = .12)

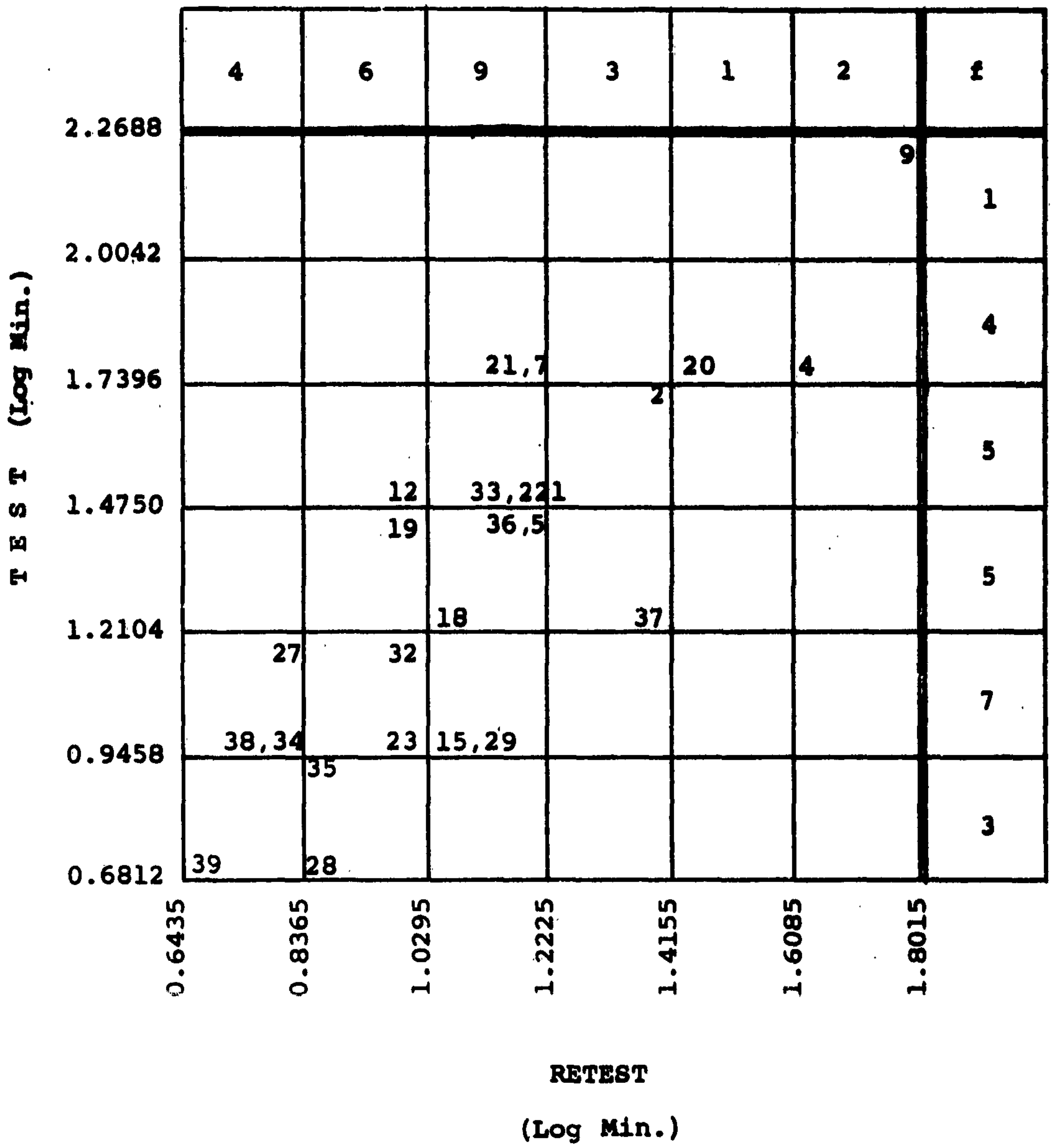

FIGURE 3.9. TEST-RETEST CORRELATION

(N = 25, r = .806)

provides a continuous range of test times. The calculated r for the selected group was determined to be .806 (5% level 0.40) which is highly significant. Distributions for test-retest are close approximations to the normal as evidenced by the f columns.

3.4.3.4.3 For the twenty-five selected technicians the composition, with respect to job classification, was as follows:

Laboratory Technician	5
Senior Laboratory Technician	12
Engineering Technician	8
	25

Examination of the job classification groups along the regression line found them to be generally positioned in accordance with their respective skill levels.

3.4.4 Final Test Phase - The five remaining tasks selected during the program development were administered to the 25 technicians possessing the greater test-retest reliability displayed in the initial test phase. Again, two administrations were made for each task. (See Appendix II for a breakdown of test-retest data for five tasks by elements. Table II-4 through II-13 provide this data.) Administration of the Electronics Maintenance Proficiency Test (EMPT) was made in the interval between the task test-retest.

3.4.4.1 Data - The information developed from this sequence is presented in Table II-14, "EMPT Scores," (Appendix II) and Table II-15, "Log Values of M_{ct}," (Appendix II). Table II-14 presents the EMPT subtest scores, subtotal, and total scores. The subtotal scores encompass subtests 1, 3, 4, 5, 6 and 7 related to verbal skills; whereas, subtotal 2, 8, 9 and 10 is a measure of performance. (To ease subsequent calculation all scores have been divided by 10.) Table II-15 (Appendix II) presents the logarithm of the observed maintenance time (M_{ct}) for six tasks including both test and retest. Use of the logarithm is dictated by the underlying log normal distri-

bution of maintenance time. In both tables, a numerical reference to the class of technicians employed has been made, plus their grouping in accordance with assigned job categories. Table 3.16, "Data - Means and Standard Deviation," summarizes the characteristics of the observed information.

3.4.4.2 Data Analysis - The final test phase analysis sought to provide answers to the following questions:

a. Is maintenance time a suitable and reliability measure of maintenance proficiency?

b. Do maintenance skills exist?

c. Can the EMPT (designed to measure maintenance skills) be related to the time criteria?

The following analysis will investigate these questions.

3.4.4.2.1 Time Criteria - Basic to the investigation being made is the suitability time as a measure of maintenance proficiency. It may be reasoned that should individual technicians or groups exhibit consistent maintenance performance with respect to time that this criteria may possess some validity. To examine this point further a correlation was made between test and retest task times and results obtained are contained in the following table:

Test \ Retest	1	2	3	4	5	6	Total
1	.019						
2		.449					
3			.503				
4				-.082			
5					.570		
6						.806	
Total							.606

TABLE 3.16

DATA - MEANS AND STANDARD DEVIATION

	Means	Standard Deviation
A. EMPT		
1. Vocabulary	15.28	5.62
2. Equipment Recognition	10.56	2.50
3. Analogies	9.16	1.65
4. Comprehension	15.08	3.25
5. Computation Problems	7.32	2.95
6. Similarities	10.36	2.45
7. Information	7.84	2.36
8. Absurdities	18.40	5.29
9. Picture Arrangement	9.60	1.91
10. Basic Skills	18.28	6.32
11. Verbal	65.04	14.17
12. Performance	56.84	10.78
13. Total	121.88	21.99
B. Test		
Task 1	1.3781	0.2300
Task 2	0.7354	0.1376
Task 3	0.8108	0.1700
Task 4	0.8676	0.2313
Task 5	0.8604	0.2516
Task 6	1.3556	0.3971
Total	1.9161	0.1990
C. Retest		
Task 1	1.0848	0.2500
Task 2	0.7187	0.2469
Task 3	0.7388	0.1482
Task 4	0.8162	0.2403
Task 5	0.7561	0.2110
Task 6	1.1170	0.2746
Total	1.7330	0.1544

It will be noted that tasks 1 and 4 did not correlate while tasks 2, 3, 5 and 6 did relate significantly. However, the high correlation obtained for task 6, it will be recalled, was obtained through the direct selection of technicians on the basis of good test-retest relations. The results failed unfortunately to provide a definite answer to the suitability of time as a measure of maintenance proficiency. At best it appears to be a marginal indication.

3.4.4.2.2 Maintenance Skills - The existence of maintenance skills was sought by establishing that significant difference exist among technician classifications and that skill requirements differ for maintenance tasks associated with part, chassis, and component replacement concepts. Additionally, the possible difference between skill requirements for equipment type was investigated. Table 3.17, "Analysis of Variance - Maintenance Time" presents the format used in this examination. Each of the variables considered is identified in the table. The results obtained are presented in Table 3.18, "Analysis of Variance - Calculation." It will be observed that significant differences were obtained for the variables: technicians category (A), test-retest (B), and replacement level (p). Additionally, a significant interactive B x p was obtained. Detailed examination of this relationship revealed that the interaction was probably due to the extremely high mean square value of the factor (p) rather than a true inter-relationship. In summary, this examination provides:

a. The three categories of technicians employed in this test possessed different maintenance capabilities (skills).

b. The test-retest cycle significantly affects maintenance time.

c. Different skills are required to accomplish maintenance at the part, circuit, and component levels.

d. Equipment type (function) does not appear to influence maintenance time.

TABLE 3.17

ANALYSIS OF VARIANCE -- MAINTENANCE TIME

			A_1				A_2				A_3			
			X_1	X_2	...	X_9	X_1	X_2	...	X_{11}	X_1	X_2	...	X_5
B_1	t_1	$p_1 p_2 p_3$			...				...				...	
	t_2	$p_1 p_2 p_3$			...				(Task Time) ...				...	
B_2	t_1	$p_1 p_2 p_3$			...				...				...	
	t_2	$p_1 p_2 p_3$			...				...				...	

A = Engineering Technician (A_1)
Senior Laboratory Technician (A_2)
Laboratory Technician (A_3)

B = Test (B_1)
Retest (B_2)

t = Radio (t_1)
Marker (t_2)

p = Component (p_1)
Chassis (p_2)
Part (p_3)

X = Technicians (1,2,...N)

TABLE 3.18

ANALYSIS OF VARIANCE - CALCULATIONS

	SS	d_f	MS	F	5% Sig.
A	1.2306	2	0.6153	11.25	Yes
B	1.3844	2	0.6922	12.65	Yes
t	0.0000	1	0.0000	0.00	
p	12.9239	2	6.4620	236.27	Yes
AxB	0.0349	2	0.0175	0.32	
Axt	0.0719	2	0.0360	0.66	
Axp	0.3794	4	0.0949	1.73	
Bxt	0.0177	1	0.0177	0.32	
Bxp	0.8569	2	0.4285	7.83	Yes
txp	0.0929	2	0.0465	0.85	
AxBxt	0.0039	2	0.0020	0.04	
AxBxp	0.0854	4	0.0214	0.39	
Axtxp	0.0580	4	0.0145	0.27	
Bxtxp	0.0191	2	0.0096	0.18	
AxBxtxp	0.0984	4	0.0246	0.45	
Residual	14.3953	263	0.0547		
Total	31.6527	299			

The possible confounding influence of the test-retest combination was considered and a separate analysis was made using test data only. The results obtained produced the same findings outlined. Within the limits of time data, to describe maintenance proficiency, it is felt that the existence of skills has been demonstrated.

3.4.4.2.3 EMPT Analysis - The examination of the relation of the EMPT to maintenance time began by reviewing the internal consistency of the test. Table 3.19, "Simple Correlation - EMPT," presents an investigation of the relationships between subtests, verbal and performance measures, and total EMPT scores. It will be noted that the test is generally well inter-correlated with the exception of subtest 2. Aside from this, the test appears to be generally consistent.

3.4.4.2.3.1 Table 3.20, "Simple Correlation - Test/Retest," examines the relationship between the EMPT and the test-retest data. In this investigation negative coefficients are sought, i.e. high EMPT score-low maintenance time. A correlation of -0.379 was obtained for total EMPT score versus total test time which did not meet the 5 percent level of significance ($r = 0.400$) for this investigation. Other coefficients within the table ranged from -0.572 to values slightly positive. Correlations with the retest data did not achieve the levels secured for the first administration. This was expected due the confounding influence of the technician's immediate experience with the tasks.

3.4.4.2.3.2 From this examination the ability of the EMPT to predict maintenance proficiency as evidenced by time has not been proven. The magnitude of the correlation coefficient achieved between total EMPT score and total task time; however, does provide some possible evidence to the concept. It must be concluded; however, that factors not measured by the EMPT bear a greater influence on maintenance time.

TABLE 3.19
SIMPLE CORRELATION r - EMPT

EMPT		Sub-tests	Verbal 1	Verbal 3	Verbal 4	Verbal 5	Verbal 6	Verbal 7	Verbal Sub-total	Performance 2	Performance 8	Performance 9	Performance 10	Performance Sub-total	Total
EMPT	Verbal	1	1	.220	.583	.429	.532	.532	.826	-.308	.476	.088	.480	.459	.757
		3		1	.331	.476	.357	.532	.529	.068	.074	.021	.215	.183	.430
		4			1	.752	.483	.692	.854	-.149	.410	.367	.475	.510	.801
		5				1	.393	.726	.795	-.116	.397	.554	.499	.559	.786
		6					1	.314	.670	-.286	.310	.085	.416	.344	.601
		7						1	.804	-.090	.336	.096	.235	.299	.664
		Sub-total							1	-.237	.483	.268	.540	.546	.912
	Performance	2								1	.074	-.143	-.029	.226	-.042
		8									1	.016	.484	.795	.701
		9										1	.244	.295	.317
		10											1	.861	.769
		Sub-total												1	.842
		Total													1

TABLE 3.20
SIMPLE CORRELATION r - TEST/RETEST

			Test							Retest						
			Radio			Marker Generator			Total	Radio			Marker Generator			Total
			Comp.	Chassis	Part	Comp.	Chassis	Part		Comp.	Chassis	Part	Comp.	Chassis	Part	
EMPT	Verbal	1	-.212	.006	-.236	.241	.085	-.239	-.227	.087	-.110	.035	-.048	.323	-.294	.078
		3	-.216	-.322	-.322	-.140	-.076	-.094	-.280	.015	.023	.158	-.058	-.116	-.087	.018
		4	-.369	-.182	-.431	.025	-.084	-.248	-.400	-.072	.051	-.070	-.252	-.087	-.322	-.259
		5	-.272	-.021	-.359	-.226	-.297	-.289	-.325	-.187	.010	-.001	-.282	-.159	-.251	-.253
		6	-.211	-.023	-..78	.102	-.050	-.248	-.284	-.095	.040	.187	-.150	-.010	-.151	-.020
		7	-.216	.163	-.277	.067	.106	-.151	-.152	-.021	.080	.072	-.088	-.054	-.156	-.011
		Sub-total	-.323	-.025	-.381	.067	-.047	-.278	-.365	-.039	-.007	.060	-.188	.051	-.305	-.077
	Performance	2	-.285	-.410	-.041	-.572	-.260	-.101	-.151	-.262	-.059	-.214	-.378	-.146	-.099	-.246
		8	-.208	-.159	-.145	-.236	-.150	-.245	-.320	-.128	.022	-.062	-.141	.032	-.271	-.130
		9	-.224	-.177	-.162	-.240	-.370	-.388	-.488	-.010	.047	-.414	-.401	.142	-.200	-.283
		10	-.169	-.264	.028	-.089	-.353	.086	-.089	-.405	.045	.156	-.333	-.116	.071	.006
		Sub-total	-.307	-.359	-.093	-.344	-.406	-.162	-.297	-.363	.032	-.065	-.425	-.061	-.195	-.188
		Total	-.358	-.192	-.291	-.125	-.230	-.259	-.379	-.203	.011	.007	-.323	.003	-.270	-.132

3.4.4.3 Summary - From the foregoing analysis, it appears that the ability of maintenance time to function as the sole measure of maintenance proficiency, as determined by the EMPT, is questionable. Further investigation is needed to determine if such factors as degree of workmanship. maintenance induced failures, performance restoration, and other quantitative measures do not also form a part of maintenance proficiency. It is felt that measures of these factors combined with the time criteria may be successfully related to technical proficiency providing the solution sought.

3.5 Other Developments

3.5.1 General - In addition to the maintainability prediction technique and the Electronic Maintenance Proficiency Test, other procedures and techniques applicable to maintainability engineering were developed or refined during Phase V. The general topics investigated include:

a. Theory and classification of maintenance

b. Maintainability planning and control

c. Maintainability design guidelines

d. Design review methods

e. Demonstration testing

f. Field data acquisition

Theory and classification of maintenance included the description of the maintenance process and the development of a system of indices for specifying and measuring maintainability. For planning and control, a general maintainability program plan was developed along with a description of the necessary tasks to be performed and the type of personnel required. Guidelines were developed for designing maintainability into an equipment for reduction of personnel and support requirements. A technique for demonstrating the maintainability achieved by an equipment design was developed and procedures for gathering maintainability data from operational equipment in the field detailed.

3.5.2 Theory and Classification of Maintenance - During the course of the field data collection program and the laboratory investigations, information relating to the basic maintenance process and to maintenance conditions was developed. Through the analysis of data from these programs and the maintenance experience of the personnel performing these analyses, a description of the maintenance process and a detailed classification system evolved. In addition, a system of maintenance indices for quantitatively describing equipment maintenance were developed.

3.5.2.1 The maintenance process and maintenance classifications were described in the Phase III and Phase IV progress reports.[3,4] During Phase V, this material was reviewed and compared with information gathered during the field validation program. In addition, comments were made by specialists in the various facets of maintainability. As a result of this review, some changes and additions were made to the original material. The resulting maintenance theory and classification is presented in Section 2, Volume II of this report.

3.5.2.2 A system of maintenance indices relating to the three general areas of time, cost and capability were previously developed and presented in the phase III progress report.[3] A review of these indices resulted in the change of the maintenance index to a manning index and the addition of an operational readiness index. In addition, methods for calculating index values and for determining the relation between specified and observed indices were more fully developed. The new list of indices and the calculation methods are presented in Section 2, Volume II of this report.

3.5.3 Maintainability Planning and Control - In order to meet maintainability design objectives, procedures for maintainability engineering must be established. These procedures must include: delegation of responsibility, program planning, design guidelines, control methods, and evaluation techniques. Design guidelines and a maintainability evaluation technique have been previously developed and presented in the phase IV progress report.[4] During Phase V, the remaining procedures

necessary for a maintainability engineering program were developed. These procedures included the identification of the tasks associated with a typical maintainability program and the relation of these tasks to the design-development cycle. Additionally, the requirements for personnel to staff such a program were detailed. The procedures developed are presented in Section 3, Volume II of this report in the form of a typical maintainability program plan.

3.5.4 Maintainability Design Guidelines - During Phase IV of this program guidelines for designing maintainability into prime equipment were developed. During Phase V, these guidelines were extended to include the personnel and support parameters. These guidelines were developed on the basis of the data collected from field maintenance activities and from laboratory investigation of the Electronic Maintenance Proficiency Test (EMPT).

3.5.4.1 Equipment Design Factors - The design guidelines developed during Phase IV were derived from information relating to the design parameter. These guidelines were ordered in accordance with their contribution to down time. These guidelines were reviewed during Phase V and were considered to be adequate based on the available data. An ordered list of design features along with guidelines for each feature is contained in Section 4, Volume II of this report.

3.5.4.2 Personnel Factors - There were 3 forms and 1 checklist used to gather information concerning maintenance personnel. These were as follows:

a. Checklist D - Scoring Personnel Coordination

b. Attitude - Motivation Test

c. Biographical Data Sheet

d. Electronic Maintenance Proficiency Test

Each of these is described in the following paragraphs.

3.5.4.2.1 Checklist D - This checklist was scored during the performance of each maintenance task, based on the interactions of the maintenance team members. There are six questions in this checklist which deal with the following topics:

a. The speed with which information is transmitted between team members

b. The validity of the information transmitted

c. The agreement as to method of task performance

d. The relative paticipation of each team member

e. The existence of personality conflicts between team members

f. Whether or not on-the-job training was given during the maintenance action

3.5.4.2.2 Attitude - Motivation Test - This is a paper and pencil test developed to assess the morale of maintenance personnel. It was given once to each technician for which time data were collected. This test consists of five subtests which measure the following characteristics:

a. Extrinsic Job Satisfaction - The job work conditions, benefits, pay, and the security derived from the job.

b. Intrinsic Job Satisfaction - The job satisfactions which are derived from direct performance of the work itself and which tend to be constant for the job, regardless of where the work is performed.

c. Social Aspects of the Job - The job aspects involved in the relationship of the technician with other technicians, especially those at a comparable level.

d. Opportunity for Advancement - The job aspects which the individual sees as potential sources of improving his economic position, status, and professional experience.

e. Supervisory Relationships - The relations that exist between the technician and his immediate supervisors.

3.5.4.2.3 Biographical Data Sheet - This is a survey form used to collect data concerning the training and experience of each maintenance technician. This form provided for the collection of the following data:

a. Pay grade

b. Date of enlistment

c. Age

d. Experience on equipment on which maintenance is being performed

e. Achievement in electronic fundamentals course

f. Airmen Classification Battery, or Airmen Qualification Examination test scores

g. Amount of formal electronics training

h. Amount of instructing experience

i. Amount of practical maintenance experience

j. Amount of supervisory experience

k. Amount of experience on specific types of equipment

3.5.4.2.4 Electronic Maintenance Proficiency Test - This is an individually administrated test, constructed to evaluate the technician's mental and motor skills important to maintenance proficiency. This test contains ten

sub-tests which are as follows:

a. Vocabulary,

b. Equipment Recognition,

c. Analogies,

d. Comprehension,

e. Computation,

f. Similarities,

g. Information,

h. Absurdities,

i. Picture Arrangement, and

j. Basic Skills.

These sub-tests are also combined into two groups for analysis purpose. These groups are the verbal group (a, c, d, e, f, and g) and the performance group (b, h, i, and j).

3.5.4.2.5 Relationships - Each of the personnel parameters measuring instruements was analyzed with respect to equipment down time. The checklist D (Scoring Personnel Coordination) data were found to be essentially single valued, thus rendering the checklist useless for further analysis. The total Attitude--Motivation Test score for 51 technicians, for which time data were available, was correlated with active down time. The resultant coefficient was - 0.06 which is not significant. Since the reliability of the sub-test scores is less than that for the total, no further analysis was made.

3.5.4.2.6 The Biographical data were also correlated with down time, and the results of this analysis are shown in Table 3.21, "Correlation Coefficients of Personnel Factors With Log Active Down Time."

TABLE 3.21

CORRELATION COEFFICIENTS OF PERSONNEL FACTORS WITH LOG ACTIVE DOWN TIME

Category	N	r	P
Age (years)	52	.08	N.S.*
Time in Service (years)	43	.15	N.S.
Practical Maintenance Experience (Months)	43	.08	N.S.
**ACB - Mechanical	19	.01	N.S.
***AQE - Mechanical	34	.13	N.S.
ACB - Electronics	19	.02	N.S.
AQE - Electronics	34	.06	N.S.
ACB - Technical Specialty	17	.44	.10 N.S.
AQE - Technical Specialty	22	-.56	.01 Sig.

* - N.S. - Not Significant

** - Airmen Classification Battery

*** - Airmen Qualification Examination

Only two of the categories approached accepted levels of statistical significance (ACB & AQE Technical Specialty). In this case the trends are in opposite directions and so tend to discredit the significance, since both tests are designed to measure the same skill. From the data available, no firm conclusions can be drawn. None of the other correlations were high enough to suggest any relationships with down time.

3.5.4.2.7 Two separate trials were made to validate the Electronic Maintenance Proficiency Test (EMPT) against the down time criterion. In the first trial the AN/FST-2 equipment at the Keesler Air Training Command was used. The EMPT was administered to 59 technicians who were subsequently timed while performing six corrective maintenance tasks on the AN/FST-2. The EMPT proved to be an internally consistent, mechanically smooth, reliably scored test. However, neither the scores on the sub-tests, nor the total score exhibited any meaningful correlations with active down time.

3.5.4.2.8 Because of difficulties encountered in performing the first trial validation, a second validation was planned. In this trial an equipment simulator and contractor technicians were used. Extreme care was taken to control all variables other than those being investigated. The results of this trial showed a definite trend toward correlation between EMPT score and down time, but the relation failed to be domonstrated significantly. The data for this trial and its analysis was previously discussed in this section.

3.5.4.2.9 Although a number of different personnel variables were investigated, only the Electronic Maintenance Proficiency Test showed any evidence of being related to the time a technician takes to locate and repair a malfunction in electronic equipment. This one relationship shows that a maintenance skill does exist, and that the equipment designer must consider the characteristics of the programmed maintenance personnel when designing electronic equipment. Paragraph 4.3, Volume II of this report describes, to a limited degree, these characteristics.

3.5.4.3 Support Factors - In this research, support parameter data were collected through the use of checklists. These checklists were: Checklist E, "Scoring Manuals, Technical Orders, and Instructions"; Checklist F, "Scoring Supply Conditions"; Checklist G, "Scoring Test Equipment and Tools"; and Checklist H, "Scoring Maintenance Organization and Facilities Status." The score distributions for each of these checklists were extremely skewed and could not easily be transformed to the normal case. Because of this situation the scores for the four checklists

were combined into one total support score which resulted in a distribution that was essentially normal. All analyses were based on this combined support score.

3.5.4.3.1 Method - To determine if a relation existed between the support parameter and down time, a correlation was performed between support score and log active down time. The correlation coefficient was found to be -0.45 which is significant at the 1% level. Since a relation was established, the next step was to find a technique for determining the relative contribution of the individual checklists.

3.5.4.3.2 A number of correlation techniques were investigated for use with the support checklists, and only one was found applicable due to the extreme concentrations of high scores. The technique selected was the contingency coefficient. The process involved in applying this technique is shown in Appendix II, Volume II, of this report. Table 3.22, "Support Checklists Contingency Coefficients," shows the coefficients calculated for each of the support checklists with log active down time. In Table 3.22, the number in the upper left corner of each cell is the observed value while the number in the lower right corner is the value to be expected if no relation exists. The results show that there is a significant relation for checklists E, F, and G and log active down time; but that there is no significant relation between checklist H and log active down time.

3.5.4.3.3 Interpretation - The data of Table 3.22 shows that the correlation trends are negative, i.e. active down time decreases as checklist score increases. The coefficients were tested for significance by determining the probability associated with the occurrence of values as large as the observed X^2 with one degree of freedom. The coefficient for checklist H is not significant. Since the coefficients for E, F, and G are essentially the same, it is concluded that these checklists are approximately equal in their contribution to down time. Checklist H shows no association with down time so its contribution is unknown. It should be noted that the contingency coefficient is only a measure of association and is not directly comparable to any of the standard correlation r's.

TABLE 3.22

SUPPORT CHECKLISTS CONTINGENCY COEFFICIENTS

Checklist E

Checklist Score	Log Active Down Time		
	0.716 - 1.665	1.665 - 2.615	Total
0-39	17 / 23.8	31 / 24.2	48
40	33 / 26.2	20 / 26.8	53
Total	50	51	101

$X^2 = 7.34$ $C = 0.26$

Checklist F

Checklist Score	Log Active Down Time		
	0.716 - 1.665	1.665 - 2.615	Total
0-39	6 / 12.4	19 / 12.6	25
40	44 / 37.6	32 / 38.4	76
Total	50	51	101

$X^2 = 8.71$ $C = 0.28$

TABLE 3.22
(Continued)

Checklist G

Checklist Score	Log Active Down Time		
	0.716 - 1.665	1.665 - 2.615	Total
0-51	21 / 28.7	37 / 29.3	58
52	29 / 21.3	14 / 21.7	43
Total	50	51	101

$X^2 = 9.61$ $C = 0.29$

Checklist H

Checklist Score	Log Active Down Time		
	0.716 - 1.665	1.665 - 2.615	Total
0-66	27 / 29.2	32 / 29.8	59
67-82	23 / 20.8	19 / 21.2	42
Total	50	51	101

$X^2 = 0.79$ $C = 0.09$

Since it could not be shown that one checklist related more significantly to down time that another (except for checklist H) an ordered feature list was not developed. However, Section 4.4 of Volume II presents a series of items to consider concerning the support environment during the design-development phase.

3.5.5 Design Review Methods - Maintainability specifications require that a formal design review program be established for each system/equipment development.[5] To fulfill this requirement, procedures for conducting maintainability design reviews and methods for analyzing equipment for maintainability improvement were developed. In addition, techniques for effecting trade-off with other system parameters were developed. These procedures and techniques were developed from the analysis of the data collected during this program and through the interview of equipment designers and maintenance specialists. The design review methods are given in Section 6, Volume II of this report.

3.5.6 Demonstration Testing - The experience and data gained from the laboratory studies conducted as part of this program were used to develop demonstration test methods. These methods were directed at fulfilling the maintainability specification requirements for demonstrating the achieved mean and maximum down time for electronic system.[5] The methods and requirements for demonstration testing are given in Section 7, Volume II, of this report.

3.5.7 Field Data Acquisition - One of the requirements for a complete maintainability engineering program is to obtain maintenance data from equipment under actual operating conditions. During the field data acquisition phases of this program, techniques were developed for gathering such data and much experience was gained in the use of these techniques. These techniques have been refined through the knowledge and data gained from the field programs and general requirements for maintenance data have been defined. The procedures and guides for gathering maintenance data at field locations are presented in Section 8, Volume II, of this report.

4. CONCLUSION

4.1 Current State of the Art

The techniques and information derived from this study should materially assist the engineer in his task of developing a system with good maintainability. These techniques will permit the quantitative treatment of the important time characteristics inherent to maintainability. Assessment of design features through the use of the checklist criteria, permits their influence on maintenance time to be determined, thus permitting alternate designs to be evaluated. Further, such evaluation provides guidance toward achieving the specified maintainability goals. Identification of the principal factors influencing maintenance task accomplishment directs design effort toward those features which will yield the greatest maintainability improvement, thus providing better use of the dollars invested.

4.1.1 The accuracy of the maintainability prediction technique is generally consistent with that achievable with related technologies. Considering the relatively short time maintainability has received intensive investigation, a major step has been made from a completely unknown quantity to the ordered discipline which has evolved. The ability to measure, specify, predict, control, and demonstrate maintainability places it within the realm of an explicit technology.

4.2 Recommendations for Continued Study

The work which must follow, should take the course of continued refinement of the technology, thus far advanced. Specifically, additional investigation should consider:

a. Improvement in design factor measurement techniques to achieve greater accuracy for the prediction technique.

b. Study of the personnel parameter to determine the complete range of characteristics which influence technical capability.

c. Investigation of the support environment to determine, to a greater degree, its relation to the design and personnel factors.

d. Determine the suitability of principles developed, for application to areas other than the ground electronic environment.

e. Investigate maintainability problems associated with mechanical, pneumatic, and hydraulic systems.

f. Develop expressions or techniques which will permit the relating of maintainability to reliability, cost, and other system parameters to be made to achieve system optimization.

g. Investigate the impact of modularization, integrated circuitry, and other new packaging techniques on maintainability.

h. Improve maintainability design guidelines to better assist the engineer in the selection of maintenance concepts, test equipment philofophy, and related planning requirements.

i. Further examine the underlying distributions associated with maintenance parameters, to determine their scope of applicability.

j. Development of more detailed indices for use by the equipment designer and development of an overall measurement for maintainability.

4.3 Summary

Significant advances have been made in understanding the nature of the maintainability problem and in developing analytical tools for quantitative treatment. However, any investigation of maintainability soon uncovers the complexity of the total problem and it is realized that only thorough and continued research will obtain a complete resolution of all problems. With the recognition of the maintenance impact on present systems and the advancing complexity of new programs, it is imperative that exploration of maintainability be continued.

REFERENCES

1. "A Research Plan for Developing Methods of Maintainability Measurement and Prediction (Phase I Report)," Contract AF30(602)-2057, RCA Service Company, A Division of Radio Corporation of America, RADC-TN-60-5, ASTIA No. AD 231090, 6 January 1960.

2. "Maintainability Measurement and Prediction Methods for Air Force Ground Electronic Equipment (Phase II Report)," Contract AF30(602)-2057, RCA Service Company, A Division of Radio Corporation of America, RADC-TN-60-221, ASTIA No. AD 247155, 15 September 1960.

3. "Maintainability Measurement and Prediction Methods for Air Force Ground Electronic Equipment (Phase III Report)," Contract AF30(602)-2057, RCA Service Company, A Division of Radio Corporation of America, RADC-TN-61-141, ASTIA No. AD 262454, 15 June 1961.

4. "Maintainability Prediction Technique (Phase IV Report)," Contract AF30(602)-2057, RCA Service Company, A Division of Radio Corporation of America, RADC-TDR-62-156, ASTIA No. AD-271199, 15 March 1962.

5. MIL-M-26513B(USAF), 23 March 1962, "Maintainability for Aerospace Systems and Equipment."

6. A. Hald, Statistical Theory with Engineering Applications, John Wiley and Sons, Incorporated, 1st Edition, New York, 1952.

7. C. H. Goulden, Methods of Statistical Analysis, John Wiley and Sons, Incorporated, 2nd Edition, New York, 1952.

8. M. J. Moroney, Facts from Figures, Penguin Books Incorporated, 3rd Edition, Baltimore, 1956.

9. E. L. Crow, F. A. Davis, M. W. Maxfield, Statistics Manual, Dover Publication Inc., 1st Edition, 1960.

10. W. J. Dixon and F. J. Massey, Introduction to Statistical Analysis, McGraw Hill Book Company, 2nd Edition, 1957.

11. S. Siegel, Nonparametric Statistics, McGraw Hill Book Company, 1st Edition, 1956.

12. G. U. Yule and M. J. Kendall, An Introduction to the Theory of Statistics.

13. Handbook of Service Instruction, Radar Set AN/FPS-6, T. O. 31P3-2FPS6-2 (2 Vol)

14. Handbook of Service Instruction, Radio Set AN/GRR-7, T. O. 31R2-2GRR7-2

15. Handbook of Service Instruction, Radio Transmitting Set AN/GRT-3, T. O. 31R2-2GRT3-2

16. Parts Catalog, Radar Set AN/FPS-6, T. O. 31P3-2FPS6-4 (2 Vol)

17. Parts Catalog, Radio Set AN/GRR-7, T. O. 31R2-2GRR7-4

18. Parts Catalog, Radio Transmitting Set AN/GRT-3, T. O. 31R2-2GRT3-4

APPENDIX I

FIELD DATA

LIST OF TABLES

TABLE I-1

FIELD DATA
Corrective Maintenance

No.	Task	Design Checklists A	Design Checklists B	Design Checklists C	Support Checklists E	Support Checklists F	Support Checklists G	Support Checklists H	Total	Maintenance Time Elements 1	2	3	4	5	6	7	8	Active Tech. Time	Delay Tech. Time	Total Tech. Time	Active Down Time	Delay Down Time	Total Down Time
1	51R01B	18	17	15	18	36	44	60	158	6.7	135.1	16.8	26.6	0.0	9.8	12.0	39.9	195.0	51.9	246.9	174.1	38.7	212.8
2	51R03B	57	20	39	40	40	50	60	190	0.0	2.1	0.0	0.7	0.0	2.1	0.0	1.3	4.9	1.3	6.2	3.4	0.0	3.4
3	51R19B	26	21	24	30	40	44	60	174	4.4	54.3	9.6	7.5	0.0	25.7	15.0	31.1	101.5	46.1	147.6	59.2	4.5	63.7
4	51R20B	58	26	39	38	40	52	60	190	0.0	4.7	0.0	0.7	0.0	0.0	0.0	4.0	5.4	4.0	9.4	2.7	2.0	4.7
5	51R23B	28	15	21	32	28	48	67	175	21.5	57.7	13.1	75.1	0.0	38.2	0.0	40.4	205.6	40.4	246.0	116.6	3.7	120.3
6	51R24B	34	16	24	34	34	52	67	187	71.7	12.0	0.7	24.5	0.0	13.7	8.5	133.6	122.6	142.1	264.7	84.4	24.9	109.3
7	51R25A	48	22	20	34	40	50	67	191	6.7	12.9	3.3	4.5	0.0	1.5	0.0	6.4	28.9	6.4	35.3	28.9	6.4	35.3
8	51R30B	54	24	21	40	40	50	67	197	0.5	32.6	0.0	1.4	0.0	3.9	0.0	1.6	38.4	1.6	40.0	20.0	0.0	20.0
9	51R31B	16	14	16	33	26	45	67	171	104.0	87.7	28.4	119.7	0.0	43.1	0.0	209.8	382.9	209.8	592.7	188.7	41.0	229.7
10	51R33A	28	28	19	32	40	50	67	189	23.2	11.0	5.3	11.3	0.0	0.3	0.0	2.3	51.1	2.3	53.4	51.1	2.3	53.4
11	51R34B	16	12	5	20	26	51	67	164	281.6	42.3	47.8	11.2	0.0	144.4	0.0	729.5	527.3	729.5	1256.8	156.9	7.0	163.9
12	51R35B	30	16	23	25	26	52	67	170	0.0	27.2	36.5	35.8	0.0	16.8	9.7	52.3	116.3	62.0	178.3	56.9	17.7	74.6
13	51R36B	44	20	26	40	24	52	69	185	8.0	8.9	0.0	12.6	0.0	8.5	0.0	11.6	38.0	11.6	49.6	27.0	0.0	27.0
14	51R37B	30	18	23	30	30	48	69	177	9.7	18.3	29.0	14.2	0.0	19.7	0.0	64.9	90.9	64.9	155.8	62.8	14.3	77.1
15	51R38B	30	11	18	32	40	50	69	191	13.6	160.0	9.5	0.0	0.0	2.8	0.0	54.7	185.9	54.7	240.6	99.2	15.0	114.2
16	51R39B	24	14	11	29	22	49	69	169	37.8	89.5	8.3	68.7	0.0	77.5	0.0	175.7	281.8	175.7	457.5	139.0	8.2	147.2
17	51R40B	20	14	6	30	36	52	72	190	310.0	4.4	37.0	2.0	0.0	1.5	14.8	89.4	354.9	104.2	459.1	224.7	1.0	225.7
18	51R42B	29	15	21	34	32	44	72	182	11.1	70.5	46.6	86.9	0.0	23.0	4.6	50.7	238.1	55.3	293.4	166.2	0.6	166.8
19	51R43B	42	26	23	36	40	52	72	200	7.8	5.2	4.8	15.2	0.0	0.0	0.0	17.8	33.0	17.8	50.8	25.5	0.0	25.5
20	51R44B	22	11	18	38	40	44	70	192	1.0	119.9	3.9	37.3	0.0	11.4	0.0	113.0	173.5	113.0	286.5	114.7	7.4	122.1
21	51R45B	18	14	15	38	40	52	70	200	68.0	199.3	10.8	13.7	0.0	18.7	0.0	280.9	310.5	280.9	591.4	207.2	11.8	220.0
22	52R02B	31	14	18	35	34	50	60	179	15.6	19.0	42.6	5.9	0.0	16.0	0.0	73.1	99.1	73.1	172.2	59.5	5.3	64.8
23	51C10B	28	15	18	36	26	44	67	173	10.2	58.4	28.6	6.1	0.0	36.6	2.2	27.4	139.9	29.6	169.5	111.3	0.0	111.3
24	51C11B	36	18	22	36	40	46	67	189	19.5	28.9	8.0	1.9	0.0	5.9	5.6	3.9	64.2	9.5	73.7	53.7	0.3	54.0
25	51C12B	22	8	16	34	40	35	80	189	30.8	273.3	15.2	5.1	0.0	34.9	12.5	256.4	359.3	268.9	628.2	293.2	6.8	300.0
26	51C13B	43	19	27	36	24	50	80	190	7.0	15.7	1.2	0.5	0.0	7.1	3.6	7.5	31.5	11.1	42.6	30.9	2.7	33.6
27	51C14B	40	16	24	36	40	48	80	204	14.6	37.7	3.5	4.5	0.0	2.7	7.2	118.2	63.0	125.4	188.4	61.9	100.9	162.8
28	51C15B	33	14	28	36	40	42	80	198	10.1	17.1	1.9	19.7	0.5	2.5	4.3	8.6	51.8	12.9	64.7	32.7	0.0	32.7
29	51C16B	32	14	24	38	32	46	80	196	8.8	59.2	6.2	1.3	0.0	8.0	6.5	54.4	83.5	60.9	144.4	75.0	13.5	88.5
30	51C17B	39	10	23	40	40	46	80	206	21.9	53.1	14.2	2.0	0.0	14.5	0.0	28.1	105.7	28.1	133.8	74.9	0.3	75.2
31	51C18B	42	13	29	40	40	48	80	208	5.1	30.2	10.1	4.8	0.0	1.8	0.0	17.3	52.0	17.3	69.3	47.9	1.6	49.5
32	51C19B	41	21	30	40	40	52	80	212	3.1	22.2	4.1	5.2	0.0	2.9	0.0	31.6	37.5	31.6	69.1	32.6	1.3	33.9
33	51C20B	41	21	31	40	40	52	80	212	3.5	21.8	1.2	2.8	0.0	3.1	0.0	13.4	32.4	13.4	45.8	27.7	0.0	27.7
34	51C21A	43	25	36	40	40	48	80	208	2.1	6.0	0.5	5.2	0.0	0.7	5.5	0.0	14.5	5.5	20.0	13.8	0.0	13.8
35	51C22B	44	20	31	40	40	52	80	212	13.3	1.4	2.0	13.7	0.0	2.2	0.0	16.4	32.6	16.4	49.0	24.5	0.0	24.5
36	51C23B	39	20	30	37	40	46	80	203	6.0	15.7	2.3	13.1	0.0	3.0	2.0	5.9	40.1	7.9	48.0	23.6	0.0	23.6
37	51C24B	33	16	24	37	40	40	80	197	13.1	52.3	2.3	13.3	0.0	4.4	0.0	7.5	85.4	7.5	92.9	57.1	0.0	57.1
38	51C26B	45	23	32	37	40	44	80	201	4.3	11.4	2.3	1.6	0.0	1.4	0.0	9.2	21.0	9.2	30.2	15.1	0.0	15.1
39	51C27B	37	19	32	37	40	50	80	207	11.0	18.5	3.3	4.2	0.0	2.6	2.2	3.3	39.6	5.5	45.1	35.9	2.1	38.0
40	51C28B	20	21	22	37	40	48	80	205	54.5	34.0	27.8	11.8	0.0	14.2	0.0	13.0	142.3	13.0	155.3	142.3	8.0	150.3
41	51C29B	22	14	18	36	25	50	80	191	15.7	103.1	45.7	29.7	4.0	84.2	7.4	30.3	282.4	37.7	320.1	221.5	14.5	236.0
42	51C30A	20	26	21	36	40	50	80	206	60.2	15.6	18.9	5.9	0.0	3.4	6.3	2.2	104.0	8.5	112.5	104.0	2.2	106.2
43	51C31B	31	13	27	36	40	42	80	198	5.8	95.3	7.1	3.2	0.0	19.0	0.0	59.1	130.4	59.1	189.5	89.0	1.0	90.0

TABLE I-1 (Cont.)

FIELD DATA
Corrective Maintenance

No.	Task	Design Checklists A	B	C	Support Scores E	F	G	H	Total	Maintenance Time Elements 1	2	3	4	5	6	7	8	Active Tech. Time	Delay Tech. Time	Total Tech. Time	Active Down Time	Delay Down Time	Total Down Time
44	51C32A	41	25	40	36	40	50	80	206	3.1	6.0	0.7	2.8	0.0	1.4	0.0	0.0	14.0	0.0	14.0	13.1	0.0	13.1
45	51C33B	35	12	24	36	40	42	80	198	16.5	28.9	10.9	37.4	0.0	4.3	0.6	62.0	98.0	62.6	160.6	76.7	2.4	79.1
46	51C34B	34	17	31	36	40	42	80	198	3.2	10.4	3.4	38.0	0.0	5.6	0.3	36.3	60.6	36.6	97.2	47.6	1.3	48.9
47	51C35B	39	21	34	36	40	48	80	204	5.9	4.0	3.3	12.7	0.0	3.0	0.2	0.0	28.9	0.2	29.1	25.9	0.2	26.1
48	51C36A	43	25	32	36	40	48	80	204	6.5	2.2	0.0	10.2	0.0	1.1	0.0	0.0	20.0	0.0	20.0	19.5	0.0	19.5
49	51C37B	43	21	31	36	40	48	80	204	12.7	6.0	1.0	4.4	0.0	4.3	0.0	3.4	28.4	3.4	31.8	18.5	1.2	19.7
50	51C38B	45	24	36	36	40	46	80	202	6.5	4.4	0.0	7.5	0.0	0.2	0.0	7.6	18.6	7.6	26.2	14.2	0.0	14.2
51	51C40B	45	23	36	36	40	50	80	206	4.0	12.9	0.8	3.5	0.0	1.3	0.0	13.5	22.5	13.5	36.0	18.0	0.0	18.0
52	51C41B	37	14	24	36	40	46	80	202	2.0	31.9	7.2	13.3	0.0	5.9	0.8	88.5	61.2	89.3	150.5	53.1	8.7	61.8
53	51C42A	32	19	20	36	40	40	80	196	21.3	22.1	3.1	28.1	0.0	13.5	0.0	0.9	88.1	0.9	89.0	88.1	0.9	89.0
54	51C43B	30	15	13	28	40	45	80	193	81.5	33.3	7.8	17.2	0.0	12.1	0.0	76.3	151.9	76.3	228.2	124.5	1.7	126.2
55	51C44B	37	21	28	36	40	48	80	204	5.0	17.2	3.6	6.0	0.0	6.1	0.0	24.1	37.9	24.1	62.0	32.8	1.7	34.5
56	51C45B	36	18	19	40	32	52	80	204	19.2	51.3	5.4	10.8	0.0	7.7	0.0	24.8	94.4	24.8	119.2	61.2	6.9	68.1
57	51C46B	27	17	21	36	40	47	80	203	39.2	54.2	9.5	11.6	0.0	8.9	6.5	58.6	123.4	65.1	188.5	90.7	0.6	91.3
58	51C47B	30	15	16	36	40	49	80	205	29.8	76.3	15.6	15.1	0.0	15.2	10.0	80.6	152.0	90.6	242.6	113.5	9.6	123.1
59	51C48B	33	23	28	36	36	45	80	197	3.5	14.3	8.7	10.7	0.0	1.8	0.0	28.5	39.0	28.5	67.5	38.8	1.8	40.6
60	52C01B	42	24	24	40	40	50	79	209	15.2	5.5	2.4	2.4	0.0	1.0	0.0	38.1	26.5	38.1	64.6	15.3	6.1	21.4
61	52C02B	50	24	24	40	40	52	79	211	12.5	11.2	2.7	0.0	0.0	3.0	0.0	37.4	29.4	37.4	66.8	23.4	10.0	33.4
62	52C03B	46	18	20	36	40	49	79	204	16.5	55.0	14.3	0.0	0.3	14.8	0.0	173.5	100.9	173.5	274.4	88.8	97.2	186.0

FIELD DATA
Preventive Maintenance

No.	Task	A	B	C	E	F	G	H	Total	1	2	3	4	5	6	7	8	Active Tech. Time	Delay Tech. Time	Total Tech. Time	Active Down Time	Delay Down Time	Total Down Time
1	51R02A	50	26	36	40	40	46	60	186	0.5	2.7	0.0	3.8	0.0	1.6	1.0	0.8	9.6	1.8	11.4	8.6	0.4	9.0
2	51R04B	47	20	25	24	40	48	60	172	3.7	22.8	0.0	1.2	0.0	3.7	0.6	8.0	31.4	8.6	40.0	19.3	1.1	20.4
3	51R05B	38	26	29	36	40	52	60	188	13.7	0.7	3.1	2.1	4.3	0.2	0.0	12.7	24.1	12.7	36.8	13.6	0.4	14.0
4	51R06B	52	26	31	40	40	52	60	192	14.6	1.2	0.0	0.0	1.0	0.0	0.0	3.9	16.8	3.9	20.7	10.4	0.0	10.4
5	51R07B	38	26	33	40	40	52	60	192	11.5	7.1	0.0	0.0	0.5	0.0	0.0	4.9	19.1	4.9	24.0	10.2	1.8	12.0
6	51R08B	42	24	29	40	40	52	60	192	5.7	4.9	0.0	1.0	4.9	0.0	0.0	11.5	16.5	11.5	28.0	10.0	4.0	14.0
7	51R09B	56	26	25	38	40	48	60	186	1.0	23.7	0.0	8.7	0.0	1.3	5.0	40.9	34.7	45.9	80.6	29.9	7.4	37.3
8	51R10B	38	26	29	36	40	52	60	188	13.4	1.4	1.1	3.2	4.1	0.7	0.0	8.1	23.9	8.1	32.0	13.8	2.2	16.0
9	51R11B	52	26	31	40	40	52	60	192	11.4	1.0	0.0	0.0	1.6	0.0	0.0	2.8	14.0	2.8	16.8	7.4	1.0	8.4
10	51R12B	38	26	29	36	40	52	60	188	9.5	4.1	0.0	1.0	0.0	0.0	0.0	0.0	14.6	0.0	14.6	7.3	0.0	7.3
11	51R13B	42	24	29	40	40	52	60	192	10.5	7.0	0.0	1.2	8.9	0.0	0.0	14.4	27.6	14.4	42.0	20.3	0.7	21.0
12	51R14A	57	28	30	40	40	50	60	190	0.2	6.0	0.0	0.0	0.0	0.6	0.0	1.0	6.8	1.0	7.8	6.8	1.0	7.8
13	51R15A	44	21	29	40	40	46	60	186	1.4	31.7	0.4	0.8	0.0	2.2	0.0	1.5	36.5	1.5	38.0	36.5	1.5	38.0
14	51R16B	59	26	35	40	40	52	60	192	0.5	5.6	0.0	0.0	0.0	0.9	0.0	5.0	7.0	5.0	12.0	4.7	1.3	6.0
15	51R17B	50	26	25	36	40	44	60	180	1.6	19.4	0.0	1.2	0.0	1.1	0.0	12.7	23.3	12.7	36.0	16.7	1.3	18.0
16	51R18B	50	26	25	36	40	44	60	180	1.0	18.1	0.0	1.6	0.0	0.7	0.0	4.8	21.4	4.8	26.2	17.7	0.0	17.7
17	51R21B	36	11	20	34	40	48	60	182	13.8	96.9	0.0	0.0	0.5	2.0	14.5	166.8	113.2	181.3	294.5	48.5	19.5	68.0
18	51R22B	36	11	16	34	40	48	60	182	13.0	146.7	0.0	0.0	7.7	0.0	9.5	225.1	167.4	234.6	[illegible]	72.7	7.3	80.0
19	51R26B	56	22	26	33	40	52	67	192	0.0	15.8	0.0	0.8	0.0	0.0	0.0	9.4	16.6	9.4	26.0	11.1	1.9	13.0
20	51R27A	48	26	31	33	30	50	67	180	0.7	14.8	0.1	0.0	0.0	6.9	0.0	0.3	22.5	0.3	22.8	22.5	0.3	22.8
21	51R28A	52	28	38	36	40	52	67	195	2.4	1.5	0.0	0.0	0.0	0.0	0.0	1.2	3.9	1.2	5.1	3.9	1.2	5.1

TABLE I-1 (Cont.)

FIELD DATA
Preventive Maintenance

		Design Checklists			Support Score					Maintenance Time Element													
No.	Task	A	B	C	E	F	G	H	Total	1	2	3	4	5	6	7	8	Active Tech. Time	Delay Tech. Time	Total Tech. Time	Active Team Time	Delay Team Time	Total Team Time
22	51R29A	50	28	37	40	40	52	67	199	4.0	3.1	0.0	0.0	0.0	0.0	0.0	4.5	7.1	4.5	11.6	7.1	4.5	11.6
23	51R32B	50	24	30	34	30	52	67	183	0.0	2.7	3.1	4.2	0.0	9.7	0.0	8.9	19.7	8.9	28.6	13.1	1.0	14.1
24	51R41B	34	14	19	33	27	48	72	180	11.6	63.1	22.6	22.6	5.7	5.4	0.0	154.0	131.0	154.0	285.0	31.4	11.6	43.0
25	52R01B	53	22	36	40	40	44	60	184	0.0	12.9	0.0	0.0	0.0	2.4	4.3	20.2	15.3	24.5	39.8	12.9	23.6	36.5
26	52R03B	55	24	38	40	40	52	60	192	0.6	20.8	0.0	0.0	0.0	7.0	0.0	36.4	28.4	36.4	64.8	17.6	14.8	32.4
27	52R04B	50	20	24	40	34	52	60	186	6.8	9.0	44.4	0.3	0.0	4.4	0.0	79.1	64.9	79.1	144.0	28.5	6.3	34.8
28	52R05B	53	21	34	36	40	52	60	188	1.7	17.6	0.0	2.6	0.0	1.6	0.0	21.5	23.5	21.5	45.0	16.5	2.9	19.4
29	52R06B	57	24	33	40	40	52	83	215	11.5	0.0	0.0	0.0	0.5	0.0	0.0	20.4	12.0	20.4	32.4	10.6	5.6	16.2
30	52R07B	60	22	34	40	40	52	83	215	0.0	17.3	0.0	0.0	0.0	0.0	0.0	40.9	17.3	40.9	58.2	14.5	8.5	23.0
31	52R08B	57	24	34	40	40	52	83	215	1.2	13.2	0.0	0.0	0.0	0.6	0.0	42.0	15.0	42.0	57.0	14.8	13.7	28.5
32	52R09B	58	26	35	40	40	52	83	215	0.6	18.7	0.0	0.0	0.0	0.0	0.0	43.1	19.3	43.1	62.4	18.8	12.4	31.2
33	52R10B	60	26	34	40	40	52	83	215	0.0	21.8	0.0	0.0	0.0	0.0	0.0	25.0	21.8	25.0	46.8	15.7	7.7	23.4
34	52R11B	57	24	31	40	40	52	83	215	1.1	11.6	0.0	0.0	0.0	0.7	0.0	24.8	13.4	24.8	38.2	12.3	6.8	19.1
35	52R12B	57	22	31	40	40	52	83	215	1.0	20.4	0.0	0.0	0.0	0.7	0.0	60.4	22.1	60.4	82.5	16.8	10.7	27.5
36	52R13B	60	26	35	40	40	52	83	215	0.0	16.7	0.0	0.0	0.0	0.0	0.0	26.1	16.7	26.1	42.8	15.9	5.5	21.4
37	52R14B	55	24	27	40	40	52	83	215	1.4	17.6	0.0	0.0	0.0	0.8	0.0	31.2	19.8	31.2	51.0	18.0	7.5	25.5
38	52R15B	57	24	27	40	40	52	83	215	0.7	18.0	0.0	0.0	0.0	0.7	0.0	21.6	19.4	21.6	41.0	12.4	8.1	20.5
39	52R16B	58	26	28	40	40	52	83	215	0.8	16.2	0.0	0.0	0.0	0.0	0.0	31.6	17.0	31.6	48.6	14.2	10.1	24.3
40	52R17B	57	24	27	40	40	52	83	215	1.1	17.9	0.0	0.0	0.0	0.6	0.0	37.0	19.6	37.0	56.6	16.0	12.3	28.3
41	52R18A	57	26	27	40	40	52	83	215	1.2	17.1	0.0	0.0	0.0	0.6	0.0	3.4	18.9	3.4	22.3	18.9	3.4	22.3
42	52R19B	57	24	27	40	40	52	83	215	1.0	26.6	0.0	0.0	0.0	0.7	0.0	34.9	28.3	34.9	63.2	22.8	8.8	31.6
43	52R20B	57	24	27	40	40	52	83	215	1.1	12.7	0.0	0.0	0.0	1.3	0.0	27.7	15.1	27.7	42.8	13.8	7.6	21.4
44	52R21B	57	24	27	40	40	52	83	215	1.0	20.8	0.0	0.0	0.0	0.6	0.0	34.2	22.4	34.2	56.6	18.7	9.6	28.3
45	52R22B	57	24	27	40	40	52	83	215	0.9	17.9	0.0	0.0	0.0	0.7	0.0	27.5	19.5	27.5	47.0	16.2	7.1	23.3
46	51C01B	37	17	28	33	40	50	67	190	5.1	9.9	1.7	16.7	0.0	3.9	3.3	8.6	37.3	11.9	49.2	25.6	0.0	25.6
47	51C02B	53	19	32	40	40	46	67	193	2.3	4.6	0.0	3.4	0.0	1.9	7.3	1.3	12.2	8.6	20.8	7.5	0.0	7.5
48	51C03A	53	23	29	36	40	46	67	189	1.3	8.3	0.0	1.1	0.0	1.5	2.1	0.0	12.2	2.1	14.3	11.3	1.8	13.1
49	51C04B	51	14	26	40	40	44	67	191	0.0	35.9	0.0	0.1	0.0	0.0	3.4	3.4	36.0	6.8	42.8	19.4	2.0	21.4
50	51C05B	53	18	28	40	40	42	67	189	1.9	18.3	0.0	0.0	0.0	0.7	0.9	14.0	20.9	14.9	35.8	17.3	0.6	17.9
51	51C06B	53	21	33	40	40	44	67	191	1.7	6.2	0.0	0.0	0.0	0.7	0.2	6.0	8.6	6.2	14.8	7.2	0.2	7.4
52	51C07B	57	19	32	40	40	50	67	197	1.0	4.8	0.0	0.0	0.0	0.3	0.3	3.0	6.1	3.3	9.4	4.4	0.0	4.4
53	51C08B	53	21	33	40	40	44	67	191	1.0	3.9	0.0	1.3	0.0	0.7	0.1	3.9	6.9	4.0	10.9	6.9	0.1	7.0
54	51C09B	57	19	32	40	40	50	67	197	1.0	2.6	0.0	0.0	0.0	0.0	0.0	1.4	3.6	1.4	5.0	2.5	0.0	2.5
55	51C25B	47	19	30	37	40	48	80	205	3.8	15.4	4.0	0.8	0.0	5.0	0.0	16.2	29.0	16.2	45.2	20.7	1.9	22.6

Note: Each task is coded as follows:
1st two digits - site identification
3rd digit - equipment (C = Commo.; R = Radar)
Next two digits - task number
Last digit - A = 1 man task; B = team task
All Maintenance Times are in minutes

TABLE I-2

FIELD DATA

PHASE V MAINTAINABILITY STUDY

Corrective Maintenance

No.	Task	M_{ct}	Log M_{ct}	A	B	C
1	51R01B	174.1	2.24080	18	17	15
2	51R03B	3.4	0.53148	57	20	39
3	51R19B	59.2	1.77232	26	21	24
4	51R20B	2.7	0.43136	58	26	39
5	51R23B	116.6	2.06670	28	15	21
6	51R24B	84.4	1.92634	34	16	24
7	51R25A	28.9	1.46090	48	22	20
8	51R30B	20.0	1.30103	54	24	21
9	51R31B	188.7	2.27577	16	14	16
10	51R33A	51.1	1.70842	28	28	19
11	51R34B	156.9	2.19562	16	12	5
12	51R35B	56.9	1.75511	30	16	23
13	51R36B	27.0	1.43136	44	20	26
14	51R37B	62.8	1.79796	30	18	23
15	51R38B	99.2	1.99651	30	11	18
16	51R39B	139.0	2.14301	24	14	11
17	51R40B	224.7	2.35160	20	14	6
18	51R42B	166.2	2.22063	29	15	21
19	51R43B	25.5	1.40654	42	26	23
20	51R44B	114.7	2.05956	22	11	18
21	51R45B	207.2	2.31639	18	14	15
22	52R02B	59.5	1.77452	31	14	18
23	51C10B	111.3	2.04650	28	15	18
24	51C11B	53.7	1.72997	36	18	22
25	51C12B	293.2	2.46716	22	8	16
26	51C13B	30.9	1.48996	43	19	27
27	51C14B	61.9	1.79169	40	16	24
28	51C15B	32.7	1.51455	33	14	28
29	51C16B	75.0	1.87506	32	14	24
30	51C17B	74.9	1.87448	39	10	23
31	51C18B	47.9	1.68034	42	13	29
32	51C19B	32.6	1.51322	41	21	30
33	51C20B	27.7	1.44248	41	21	31

TABLE I-2

FIELD DATA

PHASE V MAINTAINABILITY STUDY

Corrective Maintenance (Continued)

No.	Task	M_{ct}	Log M_{ct}	A	B	C
34	51C21A	13.8	1.13988	43	25	36
35	51C22B	24.5	1.38917	44	20	31
36	51C23B	23.6	1.37291	39	20	30
37	51C24B	57.1	1.75664	33	16	24
38	51C26B	15.1	1.17898	45	23	32
39	51C27B	35.9	1.55509	37	19	32
40	51C28B	142.3	2.15320	20	21	22
41	51C29B	221.5	2.34537	22	14	18
42	51C30A	104.0	2.01703	20	26	21
43	51C31B	89.0	1.94939	31	13	27
44	51C32A	13.1	1.11727	41	25	40
45	51C33B	76.7	1.88480	35	12	24
46	51C34B	47.6	1.67761	34	17	31
47	51C35B	25.9	1.41330	39	21	34
48	51C36A	19.5	1.29003	43	25	32
49	51C37B	18.5	1.26717	43	21	31
50	51C38B	14.2	1.15229	45	24	36
51	51C40B	18.0	1.25527	45	23	36
52	51C41B	53.1	1.72509	37	14	24
53	51C42A	88.1	1.94498	32	19	20
54	51C43B	124.5	2.09517	30	15	13
55	51C44B	32.8	1.51587	37	21	28
56	51C45B	61.2	1.78675	36	18	19
57	51C46B	90.7	1.95761	27	17	21
58	51C47B	113.5	2.05500	30	15	16
59	51C48B	38.8	1.58883	33	23	28
60	52C01B	15.3	1.18469	42	24	24
61	52C02B	23.4	1.36922	50	24	24
62	52C03B	88.8	1.94841	46	18	20

TABLE I-3

SUMS OF SQUARES, PRODUCTS, ETC.

Operation	0.01A	0.01B	0.01C	S
S_R	7.03	3.88	4.45	39.16393
SS_R	2.6055	0.7378	1.0401	75.49472
$S^2_R/22$	2.24640	0.68429	0.90011	69.71879
SSD_P	0.35910	0.05351	0.13999	5.77592
S_C	14.56	7.42	10.46	66.51243
SS_C	5.5194	1.4562	2.8912	115.30821
$S^2_C/40$	5.29984	1.37641	2.73529	110.59758
SSD_C	0.21956	0.07979	0.15591	4.71063
SP_{A-R}		1.3317	1.5992	11.18268
$S_AS_i/22$		1.23984	1.42198	12.51466
SPD_{A-R}		0.09186	0.17722	- 1.33198
SP_{A-C}		2.7515	3.9214	23.38464
$S_AS_i/40$		2.70088	3.80744	24.21052
SPD_{A-C}		0.05062	0.11396	- 0.82588
SP_{B-R}			0.8323	6.52154
$S_BS_i/22$			0.78482	6.90709
SPD_{B-R}			0.04748	- 0.38556
SP_{B-C}			2.0032	11.90686
$S_BS_i/40$			1.94033	12.33806
SPD_{B-C}			0.06287	- 0.43120
SP_{C-R}				7.15020
$S_CS_i/22$				7.92179
SPD_{C-R}				- 0.77159
SP_{C-C}				16.66371
$S_CS_i/40$				17.39300
SPD_{C-C}				- 0.72929
σ_R^2	0.01710	0.00255	0.00667	0.27504
σ_R	0.13077	0.05048	0.08165	0.52445
$\bar{s}_R$	0.31955	0.17636	0.20227	1.78018
λ_R	0.41	0.29	0.40	0.29
σ_C^2	0.00563	0.00205	0.00400	0.11777
σ_C	0.07503	0.04523	0.06323	0.34317
$\bar{s}_C$	0.36400	0.18550	0.26150	1.66281
λ_C	0.21	0.24	0.24	0.21

APPENDIX II

EMPT DATA

LIST OF TABLES

TABLE II - 1

BIOGRAPHICAL DATA

Technician			Training						Experience Before RCA			
			Military			Civilian			Military		Civilian	
No.	Date Emp.	RCA Rate	Branch	Spec. Sch.	Col. (Degree)	Tech. Sch.	Radio Sch.	Corr. Sch.	Elec. Tech.	Allied Field	Co. Elec.	Self Elec.
1	5 Mar 1956	SLT	USN 2 yrs.	EMS 10 mo.	1.5 yrs. (No)	No	No	No	2 yrs	No	6 yrs.	6 yrs.
2	22 Mar 1956	ET	USA 2 yrs.	Yes	No	No	Yes	No	2 yrs	No	5 yrs.	6 yrs.
3	18 May 1959	ET	No	No	No	No	1 yr.	3 yrs	No	No	4 yrs.	14 yrs.
4	7 May 1959	LT	USMC	Yes	No	3 yrs.	No	No	No	2 yrs.	2.5 yr.	No
5	20 Oct 1959	ET	USAF	Radar 4 mo.	2 yrs. (No)	1 yr.	No	No	4 yrs	No	No	No
6	26 Mar 1956	ET	USN 3 yrs.	VCS 4 mo.	No	No	2 yrs.	No	No	No	5 yrs.	2 yrs. (part)
7	25 June 1962	SLT	No	No	No	2 yrs.	2 yrs.	No	No	No	4 yrs.	No
8	18 June 1962	ET	USAF 6.5 yrs	Yes	No	No	2 yrs.	No	6 yrs	No	15.5 yrs.	No
9	4 Sept 1962	SLT	USA 3 yrs.	Radio 6 mo.	No	No	No	No	2 yrs	No	5.7 yr.	No
10	30 Mar 1959	SLT	USAF 4 yrs.	Radar 6 mo.	No	1 yr.	No	No	3.5 yrs.	No	3 yrs.	No
11	15 Apr 1959	SLT	USAF 4 yrs.	R&R 15 mo.	No	1 yr.	No	No	3 yrs	No	No	1 yr.
12	16 July 1956	ET	USN 2 yrs.	AECS 3 mo.	No	2.3 yrs	No	No	2 yrs	No	7 yrs.	3 yrs. (part)
13	10 Sept 1961	SLT	USA 4 yrs.	Micor. 4 mo.	1 yr. (No)	2 yrs.	No	No	Yes	No	2 yrs.	No
14	23 May 1962	ET	USAF 3 yrs.	Radio	No	No	3 yrs.	No	No	2 yrs.	10.5 yrs.	No
15	26 Oct 1959	LT	USAF 4 yrs.	No	No	1 yr.	2 yrs.	No	No	No	No	1.5 yrs.
16	17 Dec 1958	SLT	USAF	Radar 6 mo.	.5 yr. (No)	No	No	No	No	No	No	No

TABLE II-1

BIOGRAPHICAL DATA
(Continued)

Technician			Training						Experience Before RCA			
			Military		Civilian				Military		Civilian	
No.	Date Emp.	RCA Rate	Branch	Spec. Sch.	Col. (Degree)	Tech. Sch.	Radio Sch.	Corr. Sch.	Elec. Tech.	Allied Field	Co. Elec.	Self Elec.
17	20 May 1957	SLT	USN 3 yrs.	R&R 36 mo.	No	No	1 yr.	2 yrs.	No	No	No	10 yrs.
18	25 May 1959	SLT	No	No	2 yrs. (No)	No	No	No	No	No	3 yrs.	No
19	2 Sept 1958	SLT	USN 4.5 yr.	AES 18 Mo.	1 yr. (No)	No	1 yr.	No	3 yrs.	No	5.3 yr.	No
20	4 Sept 1957	LT	No	No	No	2.3 yr.	No	No	No	No	0.5 yr.	No
21	2 July 1962	SLT	USA 2 yrs.	No	1.5 yr. (No)	1 yr.	No	No	No	No	11 yrs.	No
22	16 June 1959	SLT	USA	R&R 11 mo.	No	No	.3 yr.	No	No	No	6.5 yr.	No
23	21 Sept 1959	ET	No	No	No	2 yrs.	No	No	No	No	2.5 yr.	No
24	29 Aug 1962	ET	USAF 4 yrs.	Radio 4 mo.	4.5 yrs. (No)	No	1 yr.	No	3 yrs.	No	6.5 yr.	No
25	8 Sept 1958	SLT	No	No	1 yr. (No)	No	No	No	No	No	2 yrs.	No
26	18 Feb 1957	ET	USA 2 yrs.	Missile 6 mo.	1 yr. (No)	No	No	No	No	No	6.6 yr.	No
27	4 Oct 1955	SLT	No	No	0.5 yrs.	1 yr.	No	Yes	No	No	14 yrs.	No
28	16 July 1956	SLT	No	No	.3 yr.	No	3 yrs.	No	No	No	4 yrs.	No
29	4 Sept 1959	SLT	No	No	No	2 yrs.	No	No	No	No	12-1/2 yrs.	No
30	4 May 1959	SLT	USA 2 yrs.	Radio 16 mo.	No	No	1.5 yr.	No	No	No	2.3 yr.	No
31	14 May 1962	SLT	USN 4 yrs.	No	No	No	No	No	No	No	6.5 yr.	No
32	8 Oct 1962	LT	No	No	No	No	2 yrs.	No	No	No	1.7 yr.	No

TABLE II-1

BIOGRAPHICAL DATA
(Continued)

Technician					Training				Experience Before RCA			
			Military		Civilian				Military		Civilian	
No.	Date Emp.	RCA Rate	Branch	Spec. Sch.	Col. (Degree)	Tech. Sch.	Radio Sch.	Corr. Sch.	Elec. Tech.	Allied Field	Co. Elec.	Self Elec.
33	26 Sept 1962	LT	USA 3 yrs.	No	No	No	Yes	No	No	No	3 yrs.	No
34	23 Mar 1956	ET	USN 4 yrs.	No	No	No	No	No	No	No	3 yrs.	No
35	15 Oct 1962	SLT	No	No	No	No	.3 yr.	No	No	No	6 yrs.	No
36	25 Mar 1957	ET	USA 3 yrs.	Radio 18 mo.	No	No	No	No	No	No	8 yrs.	No
37	8 Oct 1962	SLT	No	No	No	2 yrs.	2 yrs.	No	No	No	2.5 yr.	No
38	17 July 1957	ET	No	No	No	No	2.5 yr.	No	No	No	14 yr.	No
39	1 Sept 1955	ET	No	No	No	No	3.5 yr.	1 yr.	No	No	16 yr.	4 yrs. (part)
40	30 Apr 1962	SLT	USA 3 yrs.	No	No	2 yrs.	No	No	No	No	4 yrs.	No

TABLE II-2

TEST TASK 6 - ELEMENTS-N=40

Technician	Element 1	2	3	4	5	Total	Log Total
1	0.0	23.1	1.5	6.6	3.0	34.2	1.5340
2	0.0	40.5	1.4	5.2	3.0	50.1	1.6998
3	0.0	39.5	2.7	12.1	12.0	66.3	1.8215
4	0.5	30.2	0.4	31.2	3.0	65.3	1.8149
5	0.3	21.8	1.7	2.5	3.0	29.3	1.4669
6	0.0	33.3	1.7	1.4	6.0	42.4	1.6274
7	0.0	52.4	0.9	5.4	6.0	64.7	1.8109
8	0.0	37.1	0.0	2.5	6.0	45.6	1.6590
9	2.0	152.4	0.2	13.0	18.0	185.6	2.2686
10	0.0	12.9	0.3	1.2	3.0	17.4	1.2405
11	0.4	67.3	0.0	2.2	3.0	72.9	1.8627
12	0.6	21.8	1.4	6.8	6.0	36.6	1.5635
13	0.0	35.4	3.0	0.8	9.0	48.2	1.6830
14	0.6	23.3	1.1	2.6	6.0	33.6	1.5514
15	0.0	4.0	0.2	3.7	3.0	10.9	1.0374
16	0.4	8.6	0.0	4.0	3.0	16.0	1.2041
17	4.1	97.9	5.2	15.6	12.0	134.8	2.1297
18	0.0	6.2	0.0	10.2	3.0	19.4	1.2878
19	0.0	19.2	1.0	2.1	3.0	25.3	1.4014
20	0.5	40.3	1.7	14.0	3.0	59.5	1.7745
21	0.0	7.9	0.1	55.3	9.0	72.3	1.8591
22	0.0	22.3	2.9	3.0	3.0	31.2	1.4942
23	0.0	6.4	0.0	0.2	3.0	9.6	0.9823
24	0.0	2.9	0.0	0.8	3.0	6.7	0.8261
25	0.0	4.5	0.2	1.0	3.0	8.7	0.9395
26	0.6	8.6	0.0	1.6	3.0	13.8	1.1399
27	0.0	11.5	0.7	1.0	3.0	16.2	1.2095
28	0.0	1.3	0.0	0.6	3.0	4.9	0.6902
29	0.8	5.5	0.0	1.5	3.0	10.8	1.0334
30	1.3	36.8	0.0	11.5	6.0	55.6	1.7451
31	0.9	11.2	1.8	3.7	6.0	23.6	1.3729
32	0.0	5.8	0.0	3.5	3.0	12.3	1.0899
33	0.0	34.0	1.2	1.9	3.0	40.1	1.6031
34	0.0	6.9	0.0	0.8	3.0	10.7	1.0294
35	0.0	3.5	0.0	0.2	3.0	6.7	0.8261
36	1.5	14.2	0.7	0.7	6.0	23.1	1.3636
37	0.0	11.6	0.7	1.5	6.0	19.8	1.2967
38	0.0	8.1	0.0	0.6	3.0	11.7	1.0682
39	0.0	1.4	0.0	0.4	3.0	4.8	0.6812
40	0.0	11.2	0.0	0.4	3.0	14.6	1.1644
Total	14.5	988.8	32.7	233.3	192.0	1455.3	55.8538
%	0.99	67.53	2.25	16.03	13.20	100.00	

TABLE II-3

RETEST-TASK 6 - ELEMENTS-N=40

Technician	Element 1	2	3	4	5	Total	Log Total
1	0.0	16.4	0.1	1.0	3.0	20.5	1.3118
2	0.0	14.9	2.9	1.9	3.0	22.7	1.3560
3	0.0	2.2	0.0	1.5	3.0	6.7	0.8216
4	0.9	42.6	0.0	1.0	6.0	50.5	1.7033
5	0.5	11.4	0.5	0.9	3.0	16.3	1.2122
6	0.0	5.8	0.0	0.7	3.0	9.5	0.9777
7	0.0	11.2	0.2	0.2	3.0	14.6	1.1644
8	0.0	1.9	0.0	0.0	3.0	4.9	0.6902
9	1.2	46.4	1.8	7.8	6.0	63.2	1.8014
10	0.0	3.0	0.0	0.3	3.0	6.3	0.7993
11	0.0	4.2	0.0	1.2	3.0	8.4	0.9243
12	0.0	5.2	0.0	1.4	3.0	9.6	0.9823
13	0.0	4.9	0.3	0.1	3.0	8.3	0.9191
14	0.0	4.4	0.0	0.8	3.0	8.2	0.9138
15	0.0	8.0	0.2	1.5	3.0	12.7	1.1038
16	0.5	15.4	0.8	1.2	3.0	20.9	1.3201
17	0.0	1.5	0.0	0.3	3.0	4.8	0.6812
18	0.0	7.6	0.1	0.4	3.0	11.1	1.0453
19	0.0	4.0	0.0	1.7	3.0	8.7	0.9395
20	0.8	20.8	2.3	1.8	3.0	28.7	1.4579
21	0.0	11.6	0.2	0.7	3.0	15.5	1.190[illegible]
22	0.0	7.3	2.7	0.9	3.0	13.9	1.1430
23	0.0	5.9	0.0	0.6	3.0	9.5	0.9777
24	0.0	32.0	1.3	1.1	3.0	37.4	1.5729
25	0.0	12.0	0.0	0.2	3.0	15.2	1.1818
26	0.0	12.7	0.0	1.0	3.0	16.7	1.2227
27	0.0	0.9	0.0	1.8	3.0	5.7	0.7559
28	0.0	2.1	0.0	2.5	3.0	7.6	0.8808
29	0.0	5.5	0.0	2.9	3.0	11.4	1.0569
30	0.0	0.8	0.0	0.5	3.0	4.3	0.6335
31	0.0	1.2	0.0	0.6	3.0	4.8	0.6812
32	0.0	6.3	0.0	0.4	3.0	9.7	0.9868
33	0.0	9.3	0.0	1.4	3.0	13.7	1.1367
34	0.0	3.4	0.0	0.3	3.0	6.7	0.8261
35	0.0	5.2	0.0	0.1	3.0	8.3	0.9191
36	0.0	12.6	0.0	0.2	3.0	15.8	1.1987
37	0.0	14.1	0.2	0.6	6.0	20.9	1.3201
38	0.0	3.0	0.0	0.3	3.0	6.3	0.7993
39	0.0	0.9	0.0	0.5	3.0	4.4	0.6435
40	0.0	22.3	0.6	2.1	3.0	28.0	1.4472
Total	3.9	400.9	14.2	44.4	129.0	592.4	42.6994
%	0.65	67.68	2.39	7.50	21.78	100.00	

TABLE II-4

TEST TASK 1 - ELEMENTS-N=25

Technician	Element 1	Element 2	Element 3	Element 4	Element 5	Total	Log Total
1	0.0	25.7	0.2	1.6	3.0	30.5	1.4843
2	0.0	18.5	1.2	0.5	3.0	23.2	1.3655
4	3.2	49.3	5.7	2.3	12.0	72.5	1.8603
5	0.1	16.0	0.2	0.6	6.0	22.9	1.3598
7	0.0	23.4	0.2	5.3	12.0	40.9	1.6117
9	0.0	24.5	0.1	3.2	3.0	30.8	1.4886
12	0.1	9.6	1.0	0.7	6.0	17.4	1.2405
15	0.0	12.3	0.0	2.6	6.0	20.9	1.3201
18	0.0	15.5	0.4	1.6	3.0	20.5	1.3118
19	0.0	7.0	0.0	1.1	3.0	11.1	1.0453
20	0.0	31.3	0.0	8.5	6.0	45.8	1.6609
21	0.0	20.1	0.0	0.7	3.0	23.8	1.3766
22	0.0	12.8	0.1	0.3	3.0	16.2	1.2095
23	0.0	6.1	0.0	0.1	3.0	9.2	0.9638
27	0.0	9.2	0.0	2.0	6.0	17.2	1.2355
28	0.0	13.4	0.0	1.5	9.0	23.9	1.3784
29	0.0	40.6	0.0	0.9	15.0	56.5	1.7482
32	0.0	21.2	0.0	0.6	6.0	27.8	1.4440
33	0.0	8.7	0.3	0.5	3.0	12.5	1.0969
34	0.0	41.3	0.2	0.5	6.0	48.0	1.6812
35	0.0	28.4	0.4	1.6	9.0	39.4	1.5955
36	0.2	11.3	0.1	0.7	0.3	15.3	1.1847
37	0.0	19.0	1.7	0.3	6.0	27.0	1.4314
38	0.0	7.3	0.1	0.6	3.0	11.0	1.0414
39	0.0	13.1	1.0	0.3	6.0	20.4	1.3096
Total	3.6	485.6	12.9	38.6	144.0	684.7	34.4455
%	0.52	70.92	1.89	5.63	21.04	100.0	

TABLE II-5

RETEST TASK 1 - ELEMENTS-N=25

Technician	Element 1	2	3	4	5	Total	Log Total
1	0.0	5.5	0.0	1.0	3.0	9.5	0.9777
2	0.0	6.9	0.9	0.4	6.0	14.2	1.1523
4	0.8	13.8	2.7	1.1	6.0	24.4	1.3874
5	0.1	5.1	0.1	0.7	6.0	12.0	1.0792
7	0.0	10.5	0.3	0.3	6.0	17.1	1.2330
9	0.2	6.6	0.0	1.3	3.0	11.1	1.0453
12	0.1	8.7	0.7	1.0	6.0	16.5	1.2175
15	0.0	4.4	0.1	0.4	6.0	10.9	1.0374
18	0.0	27.4	2.9	0.4	6.0	36.7	1.5647
19	0.0	3.4	0.1	0.7	3.0	7.2	0.8573
20	0.3	6.2	0.1	0.8	6.0	13.4	1.1271
21	0.0	6.7	0.3	0.3	3.0	10.3	1.0128
22	0.0	9.2	0.3	1.0	3.0	13.5	1.1303
23	0.0	3.1	0.0	0.1	3.0	6.2	0.7924
27	0.0	26.5	1.2	2.4	15.0	45.1	1.6542
28	0.0	2.4	0.0	0.2	3.0	5.6	0.7482
29	0.0	6.9	0.0	0.5	3.0	10.4	1.0170
32	0.0	7.4	0.0	0.2	3.0	10.6	1.0253
33	0.0	17.4	1.2	0.9	6.0	25.5	1.4065
34	0.0	1.6	0.1	0.6	3.0	5.3	0.7243
35	0.0	4.2	0.1	0.3	3.0	7.6	0.8808
36	0.2	4.4	0.1	0.7	3.0	8.4	0.9243
37	0.0	11.9	0.2	0.4	9.0	21.5	1.3324
38	0.0	6.4	0.0	0.6	6.0	13.0	1.1139
39	0.0	1.5	0.0	0.3	3.0	4.8	0.6812
Total	1.7	208.1	11.4	16.6	123.0	360.8	26.1225
%	0.47	57.67	3.16	4.60	34.10	100.0	

TABLE II-6

TEST TASK 2 - ELEMENTS-N=25

Technician	Element 1	Element 2	Element 3	Element 4	Element 5	Total	Log Total
1	0.0	4.7	0.0	0.2	3.0	7.9	0.8976
2	0.0	3.5	0.0	0.1	3.0	6.6	0.8195
4	0.0	6.0	0.0	0.2	3.0	9.2	0.9638
5	0.0	1.6	0.0	0.2	3.0	4.8	0.6812
7	0.0	1.7	0.0	0.1	3.0	4.8	0.6812
9	0.0	4.2	0.0	0.3	3.0	7.5	0.8751
12	0.0	2.5	0.0	0.0	3.0	5.5	0.7404
15	0.0	3.7	0.0	0.1	3.0	6.8	0.8325
18	0.0	2.6	0.0	0.1	3.0	5.7	0.7559
19	0.0	1.0	0.0	0.1	3.0	4.1	0.6128
20	0.0	1.6	0.0	0.1	3.0	4.7	0.6721
21	0.0	2.3	0.0	0.3	3.0	5.6	0.7482
22	0.0	3.3	0.0	0.1	3.0	6.4	0.8062
23	0.0	1.3	0.0	0.1	3.0	4.4	0.6435
27	0.0	1.7	0.0	0.1	3.0	4.8	0.6812
28	0.0	1.7	0.0	0.1	3.0	4.8	0.6812
29	0.0	0.6	0.0	0.1	3.0	3.7	0.5682
32	0.0	1.9	0.0	0.1	3.0	5.0	0.6990
33	0.0	8.1	0.0	0.2	6.0	14.3	1.1553
34	0.0	2.2	0.0	0.1	3.0	5.3	0.7243
35	0.0	1.1	0.0	0.1	3.0	4.2	0.6232
36	0.0	2.9	0.0	0.1	3.0	6.0	0.7782
37	0.0	0.3	0.0	0.1	3.0	3.4	0.5315
38	0.0	1.1	0.0	0.1	3.0	4.2	0.6232
39	0.0	0.8	0.0	0.1	3.0	3.9	0.5911
Total	0.0	62.4	0.0	3.2	78.0	143.6	18.3864
%	0.00	43.45	0.00	2.23	54.32	100.0	

TABLE II-7

RETEST TASK 2 - ELEMENTS-N=25

Technician	Element 1	2	3	4	5	Total	Log Total
1	0.0	1.1	0.0	0.2	3.0	4.3	0.6335
2	0.0	0.9	0.0	0.1	3.0	4.0	0.6021
4	0.0	3.8	0.0	0.1	3.0	6.9	0.8389
5	0.0	0.3	0.0	0.1	3.0	3.4	0.5315
7	0.0	1.0	0.0	0.2	3.0	4.2	0.6232
9	0.0	0.6	0.0	0.1	3.0	3.7	0.5682
12	0.0	1.6	0.0	0.1	3.0	4.7	0.6721
15	0.0	1.2	0.0	0.1	3.0	4.3	0.6335
18	0.0	2.8	0.0	0.1	3.0	5.9	0.7709
19	0.0	0.5	0.0	0.1	3.0	3.6	0.5563
20	0.0	0.2	0.0	0.1	3.0	3.3	0.5185
21	0.0	2.0	0.0	0.1	3.0	5.1	0.7076
22	0.0	5.3	0.0	0.2	6.0	11.5	1.0607
23	0.0	0.1	0.0	0.1	3.0	3.2	0.5051
27	0.0	1.0	0.0	0.1	3.0	4.1	0.6128
28	0.0	4.7	0.0	0.2	3.0	7.9	0.8976
29	0.0	0.8	0.0	0.1	3.0	3.9	0.5911
32	0.0	1.6	0.0	0.1	3.0	4.7	0.6721
33	0.0	22.2	0.0	0.1	3.0	25.3	1.4031
34	0.0	0.8	0.0	0.1	3.0	3.9	0.5911
35	0.0	0.4	0.0	0.1	3.0	3.5	0.5441
36	0.0	2.1	0.0	0.8	6.0	8.9	0.9494
37	0.0	0.1	0.0	0.1	3.0	3.2	0.5051
38	0.0	0.9	0.0	0.1	3.0	4.0	0.6021
39	0.0	10.2	0.0	1.5	12.0	23.7	1.3747
Total	0.0	66.2	0.0	5.0	90.0	161.2	17.9653
%	0.00	41.06	0.00	3.10	55.84	100.0	

TABLE II-8

TEST TASK 3 - ELEMENTS-N=25

Technician	Element 1	Element 2	Element 3	Element 4	Element 5	Total	Log Total
1	0.0	2.2	0.0	0.3	3.0	5.5	0.7404
2	0.0	1.3	0.0	0.6	3.0	4.9	0.6902
4	0.0	3.9	0.0	9.7	6.0	19.6	1.2923
5	0.0	1.2	0.0	0.1	3.0	4.3	0.6335
7	0.0	1.7	0.0	0.3	3.0	5.0	0.6990
9	0.0	3.0	0.0	3.1	3.0	9.1	0.9590
12	0.0	2.1	0.0	0.4	3.0	5.5	0.7404
15	0.0	1.4	0.0	0.2	3.0	4.6	0.6628
18	0.0	2.7	0.0	0.9	3.0	6.6	0.8195
19	0.0	1.3	0.0	0.9	3.0	5.2	0.7160
20	0.0	1.9	0.0	0.4	3.0	5.3	0.7243
21	0.0	1.8	0.0	0.1	3.0	4.9	0.6902
22	0.0	7.3	0.0	3.7	3.0	14.0	1.1461
23	0.0	1.9	0.0	0.1	3.0	5.0	0.6990
27	0.0	1.2	0.0	0.4	3.0	4.6	0.6628
28	0.0	1.5	0.0	0.6	3.0	5.1	0.7076
29	0.0	1.7	0.0	0.1	3.0	4.8	0.6812
32	0.0	3.1	0.0	1.1	3.0	7.2	0.8573
33	0.0	3.2	0.0	2.3	3.0	8.5	0.9294
34	0.0	5.8	0.0	0.2	6.0	12.0	1.0792
35	0.0	1.8	0.0	0.1	3.0	4.9	0.6902
36	0.0	2.8	0.0	0.3	3.0	6.1	0.7853
37	0.0	6.3	0.0	0.5	3.0	9.8	0.9912
38	0.0	4.6	0.0	0.3	3.0	7.9	0.8976
39	0.0	2.9	0.0	0.1	3.0	6.0	0.7782
Total	0.0	68.6	0.0	26.8	81.0	176.4	20.2457
%	0.00	38.88	0.00	15.20	45.92	100.0	

TABLE II-9

RETEST TASK 3 - ELEMENTS-N=25

Technician	Element 1	2	3	4	5	Total	Log Total
1	0.0	1.5	0.0	0.4	3.0	4.9	0.6902
2	0.0	0.6	0.0	0.7	3.0	4.3	0.6335
4	0.0	5.0	0.0	0.3	6.0	11.3	1.0531
5	0.0	2.1	0.0	0.8	6.0	8.9	0.9494
7	0.0	0.8	0.0	0.3	3.0	4.1	0.6128
9	0.0	1.3	0.0	0.3	3.0	4.6	0.6628
12	0.0	3.8	0.0	0.6	3.0	7.4	0.8692
15	0.0	2.0	0.0	0.5	3.0	5.5	0.7404
18	0.0	1.4	0.0	0.3	3.0	4.7	0.6721
19	0.0	1.0	0.0	0.3	3.0	4.3	0.6335
20	0.0	3.5	0.0	0.4	3.0	6.9	0.8388
21	0.0	1.4	0.0	0.1	3.0	4.5	0.6532
22	0.0	3.4	0.0	3.4	3.0	9.8	0.9912
23	0.0	1.2	0.0	0.1	3.0	4.3	0.6335
27	0.0	1.0	0.0	0.2	3.0	4.2	0.6232
28	0.0	0.7	0.0	0.4	3.0	4.1	0.6128
29	0.0	1.2	0.0	1.5	3.0	5.7	0.7559
32	0.0	1.4	0.0	0.4	3.0	4.8	0.6812
33	0.0	7.4	0.0	0.5	6.0	13.9	1.1430
34	0.0	2.2	0.0	0.4	3.0	5.6	0.7482
35	0.0	0.7	0.0	0.3	3.0	4.0	0.6021
36	0.0	2.0	0.0	0.1	3.0	5.1	0.7076
37	0.0	0.7	0.0	0.6	3.0	4.3	0.6335
38	0.0	1.5	0.0	0.1	3.0	4.6	0.6628
39	0.0	1.2	0.0	0.7	3.0	4.9	0.6891
Total	0.0	49.0	0.0	13.7	84.0	146.7	18.4938
%	0.00	33.40	0.00	9.34	57.26	100.0	

TABLE II-10

TEST TASK 4 - ELEMENTS-N=25

Technician	Element 1	Element 2	Element 3	Element 4	Element 5	Total	Log Total
1	0.0	2.7	0.0	0.5	3.0	6.2	0.7924
2	0.0	1.6	0.0	0.1	3.0	4.7	0.6721
4	0.0	16.6	0.0	0.3	3.0	19.9	1.2989
5	0.0	0.7	0.0	0.2	3.0	3.9	0.5911
7	0.0	9.7	0.0	0.1	3.0	12.8	1.1072
9	0.0	3.7	0.0	1.2	3.0	7.9	0.8976
12	0.0	0.9	0.0	0.3	3.0	4.2	0.6232
15	0.0	2.2	0.0	0.6	3.0	5.8	0.7634
18	0.0	1.7	0.0	0.1	3.0	4.8	0.6812
19	0.0	3.0	0.0	0.3	3.0	6.3	0.7993
20	0.0	4.3	0.0	0.1	3.0	7.4	0.8692
21	0.0	1.5	0.0	0.3	3.0	4.8	0.6812
22	0.0	2.4	0.0	1.4	3.0	6.8	0.8387
23	0.0	4.7	0.0	0.2	3.0	7.9	0.8976
27	0.0	1.5	0.0	0.0	3.0	4.5	0.6532
28	0.0	4.8	0.0	2.0	3.0	9.8	0.9912
29	0.0	11.1	0.0	0.1	3.0	14.2	1.1523
32	0.0	1.5	0.0	0.0	3.0	4.5	0.6532
33	0.0	22.9	0.0	1.8	15.0	39.7	1.5988
34	0.0	5.7	0.0	0.1	3.0	8.8	0.9445
35	0.0	3.3	0.0	0.1	3.0	6.4	0.8062
36	0.0	3.9	0.0	0.2	3.0	7.1	0.8513
37	0.0	6.8	0.0	0.1	3.0	9.9	0.9996
38	0.0	3.3	0.0	0.1	3.0	6.4	0.8062
39	0.0	2.1	0.1	0.2	3.0	5.4	0.7324
Total	0.0	122.6	0.1	10.4	87.0	220.1	21.7100
%	0.00	55.70	0.04	4.73	39.53	100.0	

TABLE II-11

RETEST TASK 4 - ELEMENTS-N=25

Technician	Element 1	2	3	4	5	Total	Log Total
1	0.0	1.9	0.0	0.2	3.0	5.1	0.7076
2	0.0	2.1	0.0	0.1	3.0	5.2	0.7160
4	0.0	7.1	0.0	0.1	3.0	10.2	1.0086
5	0.0	3.1	0.0	0.4	3.0	6.5	0.8129
7	0.0	1.2	0.0	0.1	3.0	4.3	0.6335
9	0.0	3.7	0.0	0.1	3.0	6.8	0.8325
12	0.0	1.6	0.0	0.1	3.0	4.7	0.6721
15	0.0	3.9	0.0	0.1	3.0	7.0	0.8451
18	0.0	12.4	0.0	1.5	6.0	19.9	1.2981
19	0.2	2.2	0.0	0.2	3.0	5.6	0.7482
20	0.0	16.4	0.0	0.4	9.0	25.8	1.4116
21	0.0	7.3	0.0	0.1	6.0	13.4	1.1271
22	0.0	2.5	0.0	0.3	3.0	5.8	0.7634
23	0.0	1.4	0.0	0.1	3.0	4.5	0.6532
27	0.0	1.2	0.0	0.2	3.0	4.4	0.6435
28	0.0	0.9	0.0	0.1	3.0	4.0	0.6021
29	0.0	2.2	0.0	0.2	3.0	5.4	0.7324
32	0.0	5.1	0.0	0.1	3.0	8.2	0.9138
33	0.0	2.3	0.0	0.2	3.0	5.5	0.7404
34	0.0	1.5	0.0	0.1	3.0	4.6	0.6628
35	0.0	1.9	0.0	0.1	3.0	5.0	0.6990
36	0.0	15.7	0.0	0.2	6.0	21.9	1.3404
37	0.0	1.7	0.0	0.3	3.0	5.0	0.6990
38	0.0	1.1	0.0	0.2	3.0	4.3	0.6335
39	0.0	0.1	0.0	0.1	3.0	3.2	0.5051
Total	0.2	100.5	0.0	5.6	90.0	196.3	20.4019
%	0.10	51.19	0.00	2.86	45.85	100.0	

TABLE II-12

TEST TASK 5 - ELEMENTS-N=25

Technician	Element 1	2	3	4	5	Total	Log Total
1	0.0	0.8	0.0	0.2	3.0	4.0	0.6021
2	0.0	0.9	0.0	0.2	3.0	4.1	0.6128
4	0.0	8.2	0.0	3.0	9.0	20.2	1.3054
5	0.0	2.6	0.0	0.1	3.0	5.7	0.7559
7	0.0	4.2	0.0	0.5	3.0	7.7	0.8865
9	0.0	4.3	0.0	3.9	3.0	11.2	1.0492
12	0.0	1.3	0.0	0.2	3.0	4.5	0.6532
15	0.0	3.4	0.0	0.3	3.0	6.7	0.8261
18	0.0	2.1	0.0	0.3	3.0	5.4	0.7324
19	0.0	2.7	0.0	0.5	3.0	6.2	0.7924
20	0.0	4.8	0.0	0.2	3.0	8.0	0.9031
21	0.0	1.9	0.0	0.1	3.0	5.0	0.6990
22	0.0	20.8	0.0	2.8	18.0	41.6	1.6191
23	0.0	1.5	0.0	0.1	3.0	4.6	0.6628
27	0.0	0.6	0.0	0.2	3.0	3.8	0.5798
28	0.0	6.8	0.0	2.0	3.0	11.8	1.0719
29	0.0	0.8	0.0	0.6	3.0	4.4	0.6435
32	0.0	3.0	0.0	0.2	6.0	9.2	0.9838
33	0.0	14.7	0.0	1.3	3.0	19.0	1.2788
34	0.0	3.3	0.0	0.2	3.0	6.5	0.8129
35	0.0	1.3	0.0	0.1	3.0	4.4	0.6435
36	0.0	3.0	0.0	0.4	3.0	6.4	0.8062
37	0.0	4.9	0.0	0.2	3.0	8.1	0.9085
38	0.0	2.1	0.0	0.3	3.0	5.4	0.7324
39	0.0	2.8	0.0	0.5	6.0	9.3	0.9685
Total	0.0	102.8	0.0	18.4	102.0	223.2	21.5298
%	0.00	46.05	0.00	8.25	45.70	100.0	

TABLE II-13

RETEST TASK 5 - ELEMENTS-N=25

Technician	Element					Total	Log Total
	1	2	3	4	5		
1	0.0	1.2	0.0	0.3	3.0	4.5	0.6532
2	0.0	0.6	0.0	0.4	3.0	4.0	0.6021
4	0.2	4.8	0.0	0.5	6.0	11.5	1.0607
5	0.0	0.7	0.0	0.1	3.0	3.8	0.5798
7	0.0	1.3	0.0	0.2	3.0	4.5	0.6532
9	0.0	1.2	0.0	3.0	3.0	7.2	0.8573
12	0.0	1.2	0.0	0.5	3.0	4.7	0.6721
15	0.0	0.9	0.0	0.4	3.0	4.3	0.6335
18	0.0	1.4	0.0	0.2	3.0	4.6	0.6628
19	0.0	1.3	0.0	0.6	3.0	4.9	0.6902
20	0.0	1.4	0.0	0.4	3.0	4.8	0.6812
21	0.0	0.5	0.0	0.1	3.0	3.6	0.5563
22	0.0	4.1	0.0	0.1	3.0	7.2	0.8573
23	0.0	1.0	0.0	0.1	3.0	4.1	0.6128
27	0.0	0.4	0.0	0.1	3.0	3.5	0.5441
28	0.3	11.3	0.1	4.5	12.0	28.2	1.4502
29	0.0	1.1	0.0	0.1	3.0	4.2	0.6232
32	0.0	1.8	0.0	0.1	3.0	4.9	0.6902
33	0.0	3.0	0.0	0.5	3.0	6.5	0.8129
34	0.0	2.7	0.0	0.1	3.0	5.8	0.7634
35	0.0	2.0	0.0	0.1	3.0	5.1	0.7076
36	0.0	5.5	0.0	0.1	3.0	8.6	0.9345
37	0.0	3.3	0.1	0.4	3.0	6.8	0.8261
38	0.0	0.9	0.0	0.2	3.0	4.1	0.6128
39	0.0	7.9	0.0	0.7	6.0	14.6	1.1644
Total	0.5	61.5	0.2	13.8	90.0	166.0	18.9019
%	0.30	37.04	0.12	8.32	54.22	100.0	

TABLE II-14

EMPT SCORES

			1	3	4	5	6	7	Sub-Total	2	8	9	10	Sub-Total	Total
TECHNICIANS	Engineering	2	.04	.06	.12	.02	.06	.02	.32	.11	.11	.10	.19	.51	.83
		5	.13	.10	.14	.07	.05	.09	.58	.14	.23	.08	.13	.58	1.16
		12	.17	.11	.12	.05	.12	.03	.60	.10	.15	.08	.24	.57	1.17
		22	.13	.08	.16	.03	.10	.07	.57	.13	.18	.06	.12	.49	1.06
		23	.18	.11	.17	.09	.13	.09	.77	.12	.17	.10	.13	.52	1.29
		34	.18	.06	.13	.04	.07	.07	.55	.08	.20	.08	.10	.52	1.07
		36	.10	.09	.16	.08	.09	.07	.59	.12	.15	.12	.12	.51	1.10
		38	.25	.10	.22	.10	.16	.11	.94	.08	.25	.10	.23	.66	1.60
		39	.19	.10	.14	.05	.10	.07	.65	.09	.15	.12	.10	.46	1.11
	Senior Laboratory	1	.11	.08	.14	.09	.12	.05	.59	.10	.28	.12	.27	.77	1.36
		7	.06	.09	.10	.03	.08	.06	.42	.13	.16	.06	.08	.43	.85
		9	.17	.11	.13	.06	.10	.10	.67	.13	.13	.08	.26	.60	1.27
		18	.20	.12	.17	.09	.11	.10	.79	.11	.24	.10	.27	.72	1.51
		19	.20	.09	.21	.14	.09	.11	.84	.09	.21	.14	.26	.70	1.54
		21	.18	.08	.19	.09	.10	.09	.73	.11	.18	.10	.20	.59	1.32
		27	.22	.08	.16	.09	.13	.09	.77	.12	.21	.08	.23	.64	1.41
		28	.25	.08	.16	.08	.11	.08	.76	.13	.30	.10	.24	.77	1.53
		29	.15	.11	.18	.11	.11	.10	.76	.13	.21	.10	.27	.71	1.47
		35	.06	.08	.11	.06	.09	.06	.46	.14	.08	.12	.11	.45	.91
		37	.17	.11	.17	.11	.12	.10	.78	.07	.17	.10	.21	.55	1.33
	Laboratory	4	.20	.07	.13	.05	.11	.06	.62	.05	.11	.10	.16	.42	1.04
		15	.09	.09	.11	.08	.09	.07	.53	.12	.18	.10	.13	.53	1.06
		20	.13	.08	.12	.04	.13	.07	.57	.09	.23	.08	.17	.57	1.14
		32	.13	.11	.20	.10	.13	.10	.77	.09	.17	.10	.20	.56	1.33
		33	.13	.10	.13	.08	.09	.10	.63	.06	.15	.08	.09	.38	1.01
Total			3.82	2.29	3.77	1.83	2.59	1.96	16.26	2.64	4.60	2.40	4.57	14.21	30.47

TABLE II-15
LOG VALUES OF N_{ct}

TECHNICIANS		Test 2	Test 4	Test 1	Test 3	Test 5	Test 6	Test Sub-total	Retest 2	Retest 4	Retest 1	Retest 3	Retest 5	Retest 6	Retest Sub-total
Engineering	2	.8195	.6721	1.3655	.6902	.6128	1.6998	1.9713	.6021	.7160	1.1523	.6335	.6021	1.3560	1.7356
	5	.6812	.5911	1.3598	.6335	.7559	1.4669	1.8506	.5315	.8129	1.0792	.9494	.5798	1.2122	1.7067
	12	.7404	.6232	1.2405	.7404	.6532	1.5635	1.8675	.6721	.6721	1.2175	.8692	.6721	.9823	1.6776
	22	.8062	.8387	1.2095	1.1461	1.6191	1.4942	2.0652	1.0607	.7634	1.1303	.9912	.8573	1.1430	1.7903
	23	.6435	.8976	0.9638	.6990	.6628	0.9823	1.6096	.5051	.6532	.7924	.6335	.6128	.9777	1.5024
	34	.7243	.9445	1.6812	1.0792	.8129	1.0294	1.9605	.5911	.6628	.7243	.7482	.7634	.8388	1.5065
	36	.7782	.8513	1.1847	.7853	.8062	1.3636	1.8062	.9494	1.3404	.9243	.7076	.9345	1.1987	1.8370
	38	.6232	.8062	1.0414	.8976	.7324	1.0682	1.6684	.6021	.6335	1.1139	.6628	.6128	.7993	1.5599
	39	.5911	.7324	1.3096	.7782	.9685	.6812	1.6972	1.3747	.5051	.6812	.6891	1.1644	.6435	1.7451
Senior Laboratory	1	.8976	.7924	1.4843	.7404	.6021	1.5340	1.9460	.6335	.7076	.9777	.6902	.6532	1.3117	1.6884
	7	.6812	1.1072	1.6117	.6990	.8865	1.8109	2.1332	.6232	.6335	1.2330	.6128	.6532	1.1644	1.6884
	9	.8751	.8976	1.4886	.9590	1.0492	2.2686	2.4016	.5682	.8325	1.0453	.6628	.8573	.8007	1.9850
	18	.7559	.6812	1.3118	.8195	.7324	1.2878	1.7952	.7709	1.2981	1.5647	.6721	.6628	1.0453	1.9186
	19	.6128	.7993	1.0453	.7160	.7924	1.4031	1.7649	.5563	.7482	.8573	.6335	.6902	.9395	1.5353
	21	.7482	.6812	1.3766	.6902	.6990	1.8591	2.0660	.7076	1.1271	1.0128	.6532	.5563	1.1903	1.7193
	27	.6812	.6532	1.2355	.6628	.5798	1.2095	1.7084	.6128	.6435	1.6542	.6232	.5441	.7559	1.8261
	28	.6812	.9912	1.3784	.7076	1.0719	.6902	1.7803	.8976	.6021	.7482	.6128	1.4502	.8808	1.7589
	29	.5682	1.1523	1.7482	.6812	.6435	1.0334	1.9750	.5911	.7324	1.0170	.7559	.6232	1.0569	1.6128
	35	.6232	.8062	1.5955	.6902	.6435	.8261	1.8195	.5441	.6990	.8808	.6021	.7076	.9191	1.5250
	37	.5315	.9996	1.4314	.9912	.9085	1.2967	1.8921	.5051	.6990	1.3324	.6335	.8261	1.3201	1.7896
Laboratory	4	.9638	1.2989	1.8603	1.2923	1.3054	1.8149	2.3153	.8389	1.0086	1.3874	1.0531	1.0607	1.7033	2.0599
	15	.8325	.7634	1.3201	.6628	.8261	1.0374	1.7459	.6335	.8451	1.0374	.7404	.6335	1.1038	1.6503
	20	.6721	.8692	1.6609	.7243	.9031	1.7745	2.1161	.5185	1.4116	1.1271	.8388	.6812	1.4579	1.9186
	32	.6990	.6532	1.4440	.8573	.9838	1.0899	1.8195	.6721	.9138	1.0253	.6812	.6902	.9868	1.6325
	33	1.1553	1.5988	1.0969	.9294	1.2788	1.6031	2.1274	1.4031	.7404	1.4065	1.1430	.8129	1.1367	1.9562
Total		18.3864	21.6958	34.4455	20.2727	21.5098	33.8883	47.9029	17.9653	20.4027	27.1225	18.5021	18.9019	26.9247	43.3260

DISTRIBUTION LIST

RADC TDR 63-85 Vol. I AF30(602)-2057

	No. of Copies
RADC (RASGR, ATTN: F. Mazzola) Griffiss AFB NY	all remaining copies
RADC (RAAPT) Griffiss AFB NY	1
RADC (RAALD) Griffiss AFB NY	1
GEEIA (ROZMCAT) Griffiss AFB NY	1
RADC (RAIS, ATTN: Mr. Malloy) Griffiss AFB NY	1
US Army Electronics R&D Labs Liaison Officer RADC Griffiss AFB NY	1
AUL (3T) Maxwell AFB Ala	1
ASD (ASAPRD) Wright-Patterson AFB Ohio	1
Chief, Naval Research Lab ATTN: Code 2027 Wash 25 DC	1
Air Force Field Representative Naval Research Lab ATTN: Code 1010 Wash 25 DC	1
Commanding Officer US Army Electronics R&D Labs ATTN: SELRA/SL-ADT Ft Monmouth NJ	1

National Aeronautics & Space Admin Langley Research Center Langley Station Hampton Virginia ATTN: Librarian	1
RTD (RTGS) Bolling AFB Wash 25 DC	1
AFSC (SCSE) Andrews AFB Wash 25 DC	1
ASTIA (TISIA-2) Arlington Hall Station Arlington 12 VA	10
Hq USAF (AFCOA) Wash 25 DC	1
Bureau of Naval Weapons Main Navy Bldg Wash 25 DC ATTN: Technical Librarian, DL1-3	1
Redstone Scientific Information Center US Army Missile Command Redstone Arsenal, Alabama	1
ADC (ADOAC-DL) Ent AFB Colo	1
ESD (ESSTE-2/Maj Barton) L G Hanscom Fld Bedford Mass	1
Department of Defense Office of Maintenance Engineering ATTN: A. L. Jackson, Jr. ODDR&E Room 3D1018, Pentagon Wash 25 D C	1
ASD (ASMIR/Mr. Scholl) Wright-Patterson AFB Ohio	1

DCAS (MCFA/Mr. Kurth) AF Unit Post Office Los Angeles 45 Calif	1
Department of Defense OASD For Research & Engineering ATTN: Mr. E. Nucci, ODDR&E) Wash 25 D C	1
USAF (AFMME-AR/Mr. S. Hirshon) Wash 25 D C	1
AFLC (MCPE/Mr. Littler) Wright-Patterson AFB Ohio	1
USAF (AFMME-AM/Col Fallon) Wash 25 D C	1
ESD (ESRDE/Maj Van Horn) L G Hanscom Fld Bedford Mass	1
AFSC (SCSNR/Mr. Wenger) Andrews AFB Wash 25 D C	1
AFSC (SCSNR/Maj Crumpacker) Andrews AFB Wash 25 D C	1
Weapon System Evaluation Group Pentagon Wash 25 D C	1
SSD (SSSIR/Mr. John Shook) Norton AFB Calif	1
SSD (SSOCO/Capt Leslie Rutherford) Norton AFB Calif	1
ASD (MRPEM/Mr. L. T. Pope) 6570th Aerospace Medical Research Lab Wright-Patterson AFB Ohio	1